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AT
BY V. I. SOLOV'YEV, L. I. NOVIK AND I. D. MOROZOV
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COMMUNICATIONS AT SEA

By

V. I. Solov'yev, L. I. Novik and I. D. Morozov

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In this book are discussed general theoretical statements relating to the communications system as a key component in the system for controlling the fleet, to the equipping of vessels and ships (including submarines) with communications facilities and complexes, and to the organization and employment of communications with vessels (ships). These questions are discussed in the light of solving the problem of improving the effectiveness of communications.

This book has been written on the basis of domestic and foreign material and is intended for specialists concerned with questions relating to communications, scientific personnel and engineers of shipbuilding industry planning organizations.

Foreword

The role and importance of communications with vessels and ships have increased dramatically with navigation in remote regions of the global ocean, and especially with the automation of control. The effectiveness of the operation of craft and of the performance of ships and the safety of navigation depend on the capabilities and effectiveness of communications.

It is a good idea to discuss as a whole questions relating to communications with vessels. In this book the authors have attempted to generalize and systematize the key theoretical and practical questions relating to communications with vessels and ships for different purposes, uniting communications with them under the term "communications at sea." The authors have thereby taken as a starting point the similarity of conditions for carrying out communications, the common lines along which many engineering and technical questions relating to design are answered, etc.

The contents of this book are presented in accord with modern scientific views, based on the generalization of domestic and foreign know-how in equipping vessels and ships with communications facilities and complexes, and in the organization and employment of communications, including international, in conformity with conventions, regulations and other international documents relating to radio communications of the mobile marine service and the mobile marine satellite service. Questions relating to outfitting with communications facilities and complexes, and to the organization and employment of communications for submarines and surface vessels and of naval communications systems are discussed with reference to data from foreign publications.

This book has been written with reference to data from domestic and foreign publications. Chapters 1, 4, 7 and 11 and part 12.1 were written by Candidate in Naval Sciences and Assistant Professor V.I. Solov'yev, chapters 2, 3 and 6 and parts 7.5 and 12.2 by Candidate in Naval Sciences and Assistant Professor L.I. Novik, chapters 8 to 10 by Candidate in Technical Sciences I.D. Morozov, chapter 5 by I.D. Morozov and V.I. Solov'yev, and part 12.3 by L.I. Novik and V.I. Solov'yev.

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All comments and suggestions regarding the contents of this book should be sent to the following address: 191065, Leningrad, ul. Gogolya, 8, Izdatel'stvo Sudostroyeniye.

Section One

Communications Systems

Chapter 1. General Statements Concerning Control and Communications With Vessels and Ships

Problems relating to the control of transport, merchant, research and naval fleets and of vessels for different purposes have many questions in common, which makes it possible, in spite of the differences which exist, to make theoretical generalizations and to find the most intelligent solutions for them. This is the result of a great number of factors, such as the oneness of the nature and conditions of navigation and areas of navigation of vessels and ships, analogies in safeguarding navigation and coastal basing, similarity in organizational formations consisting of groups, squadrons, flotillas and the like, and analogies in questions relating to preparation for and planning of their operations and to control in the course of the accomplishment of objectives set. It is important to note that vessels complete voyages both in inland seas and around Europe and Asia and to North and South America, Australia and Antarctica, and research vessels sail in all regions of the global ocean. Thus, vessels solve the tasks set for them at great distances from on-shore control centers, and communications ranges reach 10,000 to 20,000 km [63, 72].

1.1. Control Systems; Information Flow

Marine transport, the fishing industry and the navy represent, on the plane of the problem under consideration, highly complex dynamic systems of the organization type, of which are characteristic the common properties of organizational systems and common laws of control. Each system of this sort, in spite of differences, represents a certain organized set of interrelated structural elements united by communality of action for the purpose of achieving a definite goal. This makes it possible to find common theoretical premises for analyzing and synthesizing control structures in economic systems at different levels—from ministries to production and transport associations, and, in naval systems, from the VMF [navy] to associations and formations of ships.

By control is meant the influencing of controllable systems for the purpose of achieving a set goal, i.e., a definite type of activity aimed at the

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preparation of controllable systems and the planning, organization and guidance of their activities for the purpose of accomplishing set goals and achieving the final purpose.

Control under modern conditions is impossible without complete control equipment, by means of which the data needed for planning operations are gathered, processed and analyzed, calculations are made which assist in converting information on a state into instruction information and in finding the best variant of an operations plan, tasks are delivered to their executors, their combined operations are organized, and these operations are monitored and controlled. Control facilities and the people performing all control functions comprise a control system.

The simplest system consists of the controlled process and the control agent, which are interconnected by means of a state information flow (from the controlled process to the control agent) and an instruction (directive) information flow (from the control agent to the controlled process), and represents a control circuit. A real control system contains a great number of circuits at different control levels and sections. In each control circuit and between them the exchange of information takes place in the form of messages. The travel through space of information in the form of messages represents the essence of communications as an information process taking place in a control system and uniting all its components into a single whole. By virtue of this, the combination of control facilities takes on new properties and characteristics.

Control facilities are joined in relation to their purpose and role in functioning of the control system and form subsystems, which, in the systems approach, can be regarded as independent systems. Distinguished at the present time are the system of control agencies (centers), the communications system, and, in military control systems in recent times, the system for interpreting the situation. A control system at each control level and section must embrace all controlled processes and have links with systems of higher and lower control sections, as well as with the interacting organizations and associations on the same level, of various departments and ministries. The control systems of lower levels of control are component parts of the control systems of higher levels, right up to the highest level of control. By virtue of the hierarchical nature of control systems, the subsystems of a control system are similarly subordinated, i.e., control agency (center) systems, communications systems and situation interpretation systems.

In control systems, state information travels from controlled processes (from vessels and ships) to control centers of the shipping line or fleet, and instruction, directive information, from the control center to the controlled process. The steady travel of messages in a single direction constitutes an information flow. It is characterized by parameters which it is practical to subdivide into primary and secondary.

Primary parameters characterize a flow of information created by a single source of information. They include the size of messages (q, words, groups)

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and the intensity of the flow (C, messages per unit of time), which are given for vessels and ships in tables 1.1 to 1.4, and sometimes the time interval between messages (t_{int}). These parameters represent random magnitudes; therefore, the flow is also characterized by variation factors for these parameters (γ_q, γ_s, and $\gamma_{t\ int}$). For completeness in a description of the information flow it is necessary to know also the number of kinds of messages (n_{vid}) and of so-called message series (n_{sr}), as well as the percentage of each kind and series of message (K_{vid} and K_{sr}) in terms of the whole.

Secondary parameters characterize the flow of information created by all sources of information in a specific direction (N_{ist}). Included among these parameters are the load (Y, hours busy), i.e., the maximum mean hourly or mean 24-hour load, per hour or 24-hour period (Y_{chnn} and Y_{snn}) and the maximum load concentration factor per hour or 24-hour period (K_{chnn} or K_{cnn}).

The value of Y_{chnn} is calculated by the equation in [23]:

$$Y_{\text{чнн}} = C_c K_{\text{чнн}} \left(1 + \gamma_c^2\right) t_k, \tag{1.1}$$

where C_s is the mean 24-hour intensity and t_k is the mean time a channel is engaged in transmitting a single message. It depends on the size of service calls (q_{sl}), the heading of the radio message (q_{zagl}) and the transmission rate (V_{per}), and is determined by the formula:

$$t_к = \frac{(q_{сл} + q_{заг л} + q)\left(1 + \gamma_q^2\right)}{V_{пер}}. \tag{1.2}$$

In terms of the nature of the arrival of messages, flows are divided into regular (determinate) and irregular (random). Characteristic of regular flows are specified values of parameters (e.g., the number and times for messages from cargo vessels are once and twice per 24-hour period, and from passenger and merchant vessels, twice to four times per 24-hour period [63, 72]). An example of an irregular flow can be the report of a search party on finding the object of the search.

The forecasting of regular flows does not cause any complexity: The total flow is the sum of partial regular flows.

For the purpose of forecasting irregular flows, it is necessary to establish the law for their irregularity. For example, the following has been established [39] for the flow of messages from search vessels: 1) under definite conditions the probability that m messages will be given over a specified time interval obeys Poisson's law; 2) the interval between two successive messages is a random magnitude with an exponential-law distribution; 3) the intensity of the flow of messages from a search party is numerically equal to its search potential, i.e., to the mathematical expectation of a find per unit of time.

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Table 1.1.

1) Направления связи	5) Радиограммы	9) Судно ММФ			10) Судно МРХ			11) Судно ММФ и МРХ		
		q	C_c	%	q	C_c	%	q	C_c	%
2) Берег — море	6) Международные	19,1	2,0 / 0,1	0,4	20,4	0,2 / 0,01	0	19,3	0,8 / 0,04	0,1
	7) Служебные	—	—	—	47,2	425 / 9,1	61,3	—	—	—
	8) Частные	—	—	—	22,6	267 / 11,8	38,7	—	—	—
		52,3	538 / 10,9	100	33,2	692 / 20,9	100	36,5	645 / 17,6	100
3) Море — берег	6) Международные	17,8	6 / 0,3	2,5	31,1	0,8 / 0,02	0,1	19,6	2,4 / 0,12	0,5
	7) Служебные	24,2	138 / 5,6	57,2	40,6	379 / 9,3	65,9	37,2	306 / 8,2	64,8
	8) Частные	20,2	97 / 4,8	40,3	20,1	195 / 9,6	34,0	20,1	165 / 8,2	34,7
		22,3	241 / 10,8	100	30,6	575 / 18,8	100	29,1	275 / 16,4	100
4) Общий обмен	6) Международные	18,0	8 / 0,4	1,0	30,0	1 / 0,03	0,1	19,5	3,2	0,3
	7) Служебные	—	—	—	43,9	804 / 18,3	63,5	—	—	—
	8) Частные	—	—	—	21,9	462 / 21,1	26,4	—	—	—
		37,0	779 / 21,0	100	32,1	1267 / 39,6	100	36,4	1120 / 30,7	100

[Key and notes on following page]

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Notes: 1) q is the mean size of a radiogram in words; 2) C_s is the mean 24-hour intensity of traffic: in words in the numerator and in radiograms in the denominator.

Key:

1. Direction of communication
2. Shore to ship
3. Ship to shore
4. General traffic
5. Radiograms
6. International
7. Service
8. Private
9. MMF [Ministry of the Maritime Fleet] vessel
10. MRKh [Ministry of Fisheries] vessel
11. MMF and MRKh vessel

Table 1.2.

1) Направления связи	5) Флагманский корабль соединения		6) Надводный корабль		7) Подводная лодка		8) Торпедный катер	
	q	C_c	q	C_c	q	C_c	q	C_c
2) Берег — море	54,4	2394/43,9	32,9	106,8/3,27	28,8	89,1/3,2	15,0	231/14
3) Море — берег	35,4	1355/38	42,7	392,8/9,2	24,7	9,8/0,4	18,2	241/13,7
4) Общий обмен	45,7	3749/81,9	40,0	499,6/12,47	26,7	98,9/3,6	16,6	472/27,7

Key:

1. Direction of communications
2. Shore to ship
3. Ship to shore
4. General traffic
5. Formation flag ship
6. Surface vessel
7. Submarine
8. Torpedo boat

Table 1.3.

1) Направления связи	5) Вне всякой очереди			6) Экстренная			7) Срочная			8) Обыкновенная		
	q	C_c	%	q	C_c	%	q	C_c	%	q	C_c	%
2) Берег — море	25,4	11,1/0,44	13,5	31,3	55,0/1,72	52,5	33,6	30,5/0,91	27,9	51	10,2/0,2	6,1
3) Море — берег	20,8	22,3/1,07	11,6	46,5	235/5,05	55	38,4	93,5/2,43	26,4	64,3	42/0,65	7,0
4) Общий обмен	22,1	33,4/1,51	12,3	42,8	290/6,77	54,2	34,1	124/3,34	26,8	61,4	52,2/0,85	6,7

Notes: q is the mean size of a radiogram in groups; C_s is the mean 24-hour intensity of traffic: in groups in the numerator and in radiograms in the denominator.

[Key on following page]

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Key:
1. Direction of communications
2. Shore to ship
3. Ship to shore
4. General traffic
5. Out of any order
6. Urgent
7. Routine
8. Ordinary

Table 1.4.

1) Направления связи	5) Время осуществления связи	Надводные корабли		Подводные лодки	
		8) q	C_c	9) q	C_c
Берег—море 2)	Мирное 6)	45,7	1600/35	37,5	450/12
	Военное 7)	45,0	6500/140	36,9	960/26
Море—берег 3)	6) Мирное	45,0	900/20	25,0	125/5
	7) Военное	27,7	1500/54	15,3	143/8
Общий обмен 4)	6) Мирное	45,4	2500/55	33,8	575/17
	7) Военное	41,2	8000/194	32,4	1103/34

Note: q is the mean size of a radiogram in groups; C_s is the mean 24-hour intensity of traffic: in groups in the numerator and in radiograms in the denominator.

Key:
1. Direction of communications
2. Shore to ship
3. Ship to shore
4. General traffic
5. Time communications carried out
6. Peacetime
7. Wartime
8. Surface vessels
9. Submarines

For information flows as a whole, it is possible to use the law for the distribution of the probability of the appearance of n_s messages over interval of time t, i.e., $P_{n_s}(t)$--the Poisson or determinate law, meaning that $\sigma^2 = 0$.

For the distribution of the time between the appearance of messages, it is possible to use Erlang's n-th order law, since when $n = 0$ it makes it possible to describe the distribution of the time interval between the arrival of messages obeying an exponential law, e.g., in the transmission of messages in the ship to shore direction, and when $n \to \infty$ it makes it possible to describe a determinate flow, e.g., in transmission in the shore to ship direction.

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Information flows in each direction are forecast (determined) in relation to the method of information transmission, whereby first a determination is made of primary and then of secondary flow parameters.

The values of information flow parameters depend on a great number of factors. They can be arrived at from an analysis of statistical data on flows circulating in the control system by solving the same problems under similar conditions, or by physical, mathematical modeling of the entire or partial control process by solving problems formulated under specified conditions.

Statistical data on information flows are gathered for a voyage, for the navigation of vessels in relation to the regions in which they sail, and for a shipping line as a whole. Such generalized data are convenient for a comparative estimate of information flows in terms of vessels, voyages, sailing areas, and shipping lines. For example, on the basis of reports from vessels of the Baltic Maritime Shipping Line for 1969-1970 and of data from Giprorybflot [State Planning Institute of the Fishing Fleet] on MRKh vessels for 1966-1968, information has been put together [72] on the amount of radio traffic for MMF and MRKh vessels, by means of which have been calculated the information flow parameters for the shore to ship and ship to shore directions given in table 1.1.

It is feasible to gather and analyze information flows in the control of ships under everyday conditions and in exercises and combat operations. For example, parameters of information flows for TOF [Pacific Ocean Fleet] ships in the Great Patriotic War are given in tables 1.2 and 1.3.* An analysis of information flows for U.S. Navy ships during the war in Vietnam is given by the authors in [68].

Modeling of the process of controlling vessels and ships makes it possible to determine with a certain degree of approximation the number of messages during a specific period of operations, the need for the transmission of which is caused by the goals and nature of the operations of the controlled units (for wartime situations and by enemy operations), changes in the situation, and also the reaction of vessels (or ships) and the agency controlling them, to these changes. All these messages we will term operating information ($Y_{оп}$). As experience has shown, almost always the need arises for political information ($Y_{пол}$), for additional recommendations, instructions, explanations, requests, etc. ($Y_{доп}$), and also for service information ($Y_{сл}$). Thus, actually the sum of these flows will be transmitted, which will make up the control information flow:

$$Y_{у} = Y_{оп} + Y_{пол} + Y_{доп} + Y_{сл}. \qquad (1.3)$$

*Parameters calculated from reports of the TOF communications division. "Arkhiv GSh VMF" [Archives of the VMF General Staff], f. 129 [folio 129], d. 34090 [file 34090]. Order of radiograms given for surface vessels.

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An analysis of information flows of MMF and MRKh vessels and VMF ships has shown that these parameters are close, especially in the sizes of radiograms. The mean 24-hour volume of information transmitted in the shore to ship direction as a rule is considerably greater than in the ship to shore. Radio traffic is distinguished according to types of vessels and classes of ships and the types and nature of their operations.

Information flows increase considerably in wartime. In particular, the rise in the volume of information between the TOF staff and surface vessels and submarines during wartime is given in table 1.4.* For example, for the shore to surface vessel direction, C_s increased fourfold, and the total volume by a factor of 3.5. Traffic with submarines increased twofold. The participation of the U.S. Navy in the war in Vietnam was characterized also by a more than fourfold increase in radio traffic, which reached very high figures. For example, in 1967 in the ship to shore direction through just three key communications centers (the Phillipines, Guam and Japan) 9000 messages were transmitted in a 24-hour period [68].

It must be emphasized that for modern control systems large volumes of flow in the ship to shore, and especially in the shore to ship, direction are the rule. According to the data of statistical analysis of radiograms carried out in 1966 at the computing center of the Baltic Shipping Line, the 24-hour traffic for vessels equaled 23 million characters [72]. A trend toward an increase in information flows has been clearly pronounced also in naval fleets, especially in the tactical unit for controlling forces. For example, in the U.S. Navy during recent years the annual growth in messages has equaled eight to 10 percent [102], and the information flow between English ships has doubled in each past decade.

1.2. Communications Channels; Communications Requirements

The movement through space (traffic) of information in a control system, from the viewpoint of communications equipment, is similar both for state information and for instructional, directive information, because it always moves from a transmission center to a reception center by means of communications facilities.

By a communications facility is meant the equipment performing certain functions in the transmission and reception of messages. The combination of communications facilities taking part in the transmission and reception of messages comprises a communications channel. A channel includes a communications line--the physical medium in which signals travel from the transmission center to the reception center. Each communications channel includes facilities designed for a) converting the signals in which the message transmitted at the transmission center is "written" into signals which can be used in the communications channel in question; b) transmitting signals along the communications line from the

*"Arkhiv IO [Quartermaster Section] GSh VMF," f. 129, d. 34090, l. 31.

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transmission center to the reception center; c) converting signals used in the communications channels at the reception center into signals convenient for reception by the addressee.

At the transmission center the conversion of signals includes three operations: changing of the physical nature of the signal, coding and modulation. Coding is structuring of the signal according to a definite principle, a code used in the channel in question. Corresponding to each transmitted digit, letter, symbol or group (block) is a certain combination of distinguishable elementary signals whereby it is possible to unambiguously recreate that digit, letter, symbol or group (block). This rule of association of symbols and blocks of them with combinations of signals is called a code in coding theory. Modulation is the effect of the coded signal carrying information in keeping with the message transmitted, on a certain parameter of the signal, the carrier of the information from the transmission center to the reception center. Types of modulation are distinguished in terms of information carriers and the parameters changed (i.e., modulated).

Modulated signals (information carriers) are transmitted from the transmission center by a transmitter and are received by a receiver at the reception center. Connection of the communications line with the transmitter and receiver is accomplished by means of matching equipment, in particular, in radio receivers and radio transmitters, by means of antennas and feeders--antenna-feeder units.

At the reception center, the conversion of signals includes four operations: selection, detection, decoding and changing of the physical nature of signals. Selection is the isolation of the needed carrier signals from all those simultaneously having arrived at the receiver. Detection is the isolation from the modulated signals (carriers), after their selection, of signals carrying the message, i.e., a process the reverse of modulation. Decoding is the recreation of digits, letters, symbols or groups of them (block) from the detected signals according to the code for the channel in question, i.e., a process the reverse of coding. Changing of the physical nature of signals (into electrical and non-electrical) is as a rule carried out simultaneously with coding and decoding, respectively, in so-called terminal equipment, which for convenience can be great distances away from transmitters and receivers, being connected to them by means of switching and connecting equipment.

The make-up of facilities and their connection in the communications channel, as well as the transmission of signals, are illustrated in fig 1.1. The communications facilities of each vessel, ship, on-shore radio station and radio center comprise the transmitting or receiving line of a communications channel and thus take part in the transmission of messages from the transmission center to the reception center.

Modern communications channels can also contain other facilities. In particular, as reported in foreign publications, transmitting and receiving lines contain automatic information restriction equipment. An automatic coder in the transmitting line recodes signals in secret code and information-restricted

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signals enter the transmitter. An automatic decoder in the receiving line declassifies them.

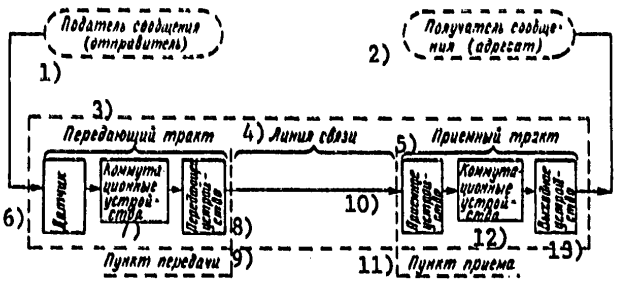

Figure 1.1. Diagram of Communications Channel

Key:

1. Issuer of message (sender)
2. Receiver of message (addressee)
3. Transmitting line
4. Communications line
5. Receiving line
6. Sensing unit
7. Switching equipment
8. Transmitting equipment
9. Transmitting center
10. Receiving equipment
11. Reception center
12. Switching equipment
13. Output unit

Each communications facility included in a channel is characterized by individual technical parameters: by the frequency range of the transmitter and receiver, by frequency instability, by the power of the transmitter and sensitivity of the receiver, etc. The technical parameters of communications facilities determine the technical parameters of communications channels, which makes it possible to compare communications channels, but only similar ones. But in analyzing and synthesizing communications systems, in solving problems of organization, and in using communications it is necessary to compare different communications channels in terms of their parameters and the possibility of employing them for the purpose of ensuring control under specific conditions. In the theory and practice of marine communications, for this purpose are employed the following key indicators of a communications channel: communications range; frequency range; kinds of communication (type of operation)--telephone, telegraph, printing, telecoding, facsimile telegraphy, etc.; transmission rate; throughput; frequency band occupied by the channel; noise rejection; weight and dimensions of equipment and the area required for installation; power requirement; cost; and, for mobile and portable facilities, scanning time, time for entry into communication.

The general properties of a communications channel can be rated by three key parameters: operating period, T_k, i.e., the time during which the channel

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performs its functions; passband, F_k, i.e., the band of frequencies admitted by the channel without considerable attenuation; and dynamic power range, Q_k, where $Q_k = \log P_s/P_p$, determined by the maximum possible power of the signal, P_s, and the power of the noise, P_p, in the channel. The product of these parameters is called the channel's capacity, $V_k = T_k F_k Q_k$, which characterizes the ability to transmit a signal in the channel in question. The properties of a signal from this point of view are described by similar parameters: by the length of the signal, T_s; by the breadth of the spectrum, F_s; and by the degree to which the signal exceeds the noise, $Q_s = \log P_s/P_p$, characterizing the ratio of the mean power of the signal and noise in transmission. The product of these parameters is called the volume of the signal, $V_s = T_s F_s Q_s$.

A communications channel can be acknowledged as satisfactory for the transmission of a particular signal if it has a capacity which will hold the signal volume, i.e., $V_k \geq V_s$. The parameters of communications channels are illustrated in Appendix 1.

Matching of the signal and communications channel must be achieved for each channel in the communications system, because for the purpose of fulfilling its purpose, the communications system must transmit in the required directions all the assigned information flows, and with the required quality.

The quality of any object or phenomenon, as follows from Marxist dialectics, is the totality of the properties of this object or phenomenon. Marine communications has the following key properties: reliability, fidelity, efficiency or speed; and naval communications must also possess secrecy. These properties in combination comprise the quality of communications.

Each property of communications can be evaluated quantitatively by the value of an individual communications indicator, e.g., the efficiency (speed) of communications by the time a message travels. The requirement for a specific property of communications can be expressed quantitatively by the permissible value of a communications indicator. By the permissible value of a communications indicator is meant that value whereby the worsening of control has not yet begun and the value of the criterion for the effectiveness of the operations of the controlled vessels or ships remains within the range of the level established.

The permissible values of communications indicators can be determined in several ways.

In practice, most frequently a determination is made of communications requirements on the basis of gathering and analyzing values of communications indicators obtained in ensuring control over vessels and ships during the performance of typical operations. After the gathering of data, communications indicators are grouped by kinds of vessel and ship, problems to be solved, operating conditions and directions of communication. It is then determined with which values of communications indicators control will be successful and the problems posed will be solved, and with which values control will be deemed unsuccessful or goals will not be fulfilled at the fault of communications.

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The first group of values of communications indicators is given a favorable rating and as the result of further analysis from this group are selected the permissible values, since they are consistent under specific conditions with successful control and the required effectiveness of operations.

In cases of the lack of sufficient material on traffic statistics and of experience in utilization of the control system, the permissible values of communications indicators can be arrived at by comparing a quantitative estimate of a specific property of communications (e.g., reliability or efficiency) with estimates of similar properties of other information processes in the control system. It is necessary here that the value of the communications indicator be better than the indicators for related information processes (procuring and gathering information on a state, analyzing, processing, representing, etc.) by virtue of the principle of anticipation of development and improvement of the communications systems in relation to other subsystems of the control system. The value of this lead depends on the importance of the information transmitted in the control system in terms of the effectiveness of the operations of the vessels and ships being controlled. By virtue of this, it is established by the individual whose duty it is to make decisions regarding the creation, improvement and organization of the control system.

For future communications systems or for systems on the experience of employing which there is no data, the permissible values of communications indicators are determined by modeling the operations of forces, taking into account the influence of the communications property in question on the effectiveness of operations. Here it is necessary that the criterion for the effectiveness of operations be critical in terms of the communications indicator. By modeling the operations of controlled processes under identical conditions, but with different values of the communications indicator (by varying them from the minimum to the maximum possible under specific conditions), it is possible to make a determination of the numerical dependence of the effectiveness of their operation on the value of the communications indicator. The results obtained make it possible to plot a graph of this dependence, from which, for a specified value of the effectiveness of the operations of vessels and ships, a determination is made of the permissible value of the communications indicator.

Specific examples of determining quantitative requirements for communications, in particular, the permissible time for the travel of reports, orders and information in the control of forces in an operations and tactical unit, are discussed in naval literature.

In modern communications systems, and even more so for future ones, the requirements for communications are high, and they continue to increase, especially with the automation of control and the creation of automated communications systems.

But it should be mentioned that the specific permissible values of communications indicators must be set by taking into account the feasibility of technical realization. For example, for the future naval communications system

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the confidence must be 10^{-5} to 10^{-6} and the transmission rate 300 to 400 bauds [48]. The communications system must guarantee stability of operation, eliminate delays and malfunctions and operate for a long time without failure [48].

The requirements for communications with MMF vessels and vessels of other departments and with other controlled units in these industrial control systems must be consistent with the high requirements of the Unified Automated System of Countrywide Communications (YeASS) which has been created in the Soviet Union [48].

1.3. Structure of Communications Systems; Communications Service

For the purpose of carrying out outside communications, each vessel and ship has the required communications facilities, the organized interconnection of which with service personnel is accomplished on vessels by radio stations (marine radio stations), and on ships by military communications units.

On shore, the facilities and communication personnel comprise communications stations, centers and units. Communications stations unite communications facilities for two-way communications (e.g., radio stations, telephone exchanges, telegraph exchanges, etc.). Communications centers unite ordinarily identical communications facilities or facilities for one kind of communications (a radio receiving center--a PRTs, a radio transmitting center--a PDRTs, a telephone center, etc.). Communications units (US's) include different facilities and make possible various kinds of communication and can include communications centers and stations, whereby PRTs's and PDRTs's are located as a rule at distances from control centers (PU's) and from one another, which ensure high-quality radio reception during the simultaneous operation of radio reception and radio transmitting equipment, and, in naval systems, for the purpose of ensuring secrecy and stability. Sometimes the PRTs and PDRTs make up a single radio center (RTs), e.g., the radio center of a shipping line. PRTs's, PDRTs's and PU's located at a distance are connected by multichannel intercenter communications lines, whose channels are designed for transmitting messages, as well as for joining terminal equipment located at PU's to PRTs receivers and PDRTs transmitters, for the purpose of remote control of monitoring equipment and other service purposes. Thus, the facilities of PU's and subdivisions of PRTs's, PDRTs's and RTs's form an organized union of equipment for the purpose of communications with vessels, which is often called a marine communications system.

In addition, the communications stations and centers of the PU's of ports and shipping lines for a single sea (or basin) are interconnected by communications lines and to central administrations and the ministry, forming a so-called shore communications system. Of course, marine communications systems and the shore system are closely interrelated and represent components of port, shipping line and ministry communications systems, respectively. Similarly are formed the communications systems of naval bases, forces, fleets and the VMF. It should be mentioned that by virtue of the hierarchical nature

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the communications systems of the MMF and MRKh are included as industrial systems in the State communications system, and the communications system of the VMF, in the communications systems of the armed forces.

Thus, by a communications system must be understood a combination of units, centers, stations and communications lines servicing on-shore control centers and subdivisions and communications units of vessels and ships, organized for the purpose of exchanging information in the performance of set objectives. Or, in other words, the communications system of a fleet consists of a combination of all communications manpower and equipment, united by a communality of organization and employment procedure. A modern communications system represents also unity in the technical policy for designing the system and developing and utilizing all its elements. A communications system must possess stability, flexibility and noise rejection, and, finally, throughput.

Required in marine transport, marine fisheries and, even more so, in VMF communications systems is the continuous round-the-clock and year-round ensurance of control, i.e., they must be constantly operating communications systems. For example, the constantly operating communications system of the VMF must ensure the gathering of information from numerous forces and facilities at work on the water, under water and in the air at enormous distances from command centers; the distribution of information received between command centers and within them; the transmission of orders, instructions and commands to its own forces and of information to interacting troops; and the notification of its own forces regarding the situation in seas and oceans and enemy operations [39, 74]. The communications system of the maritime fleet must ensure navigation safety and the protection of human life, property and cargo; and efficient supervisory guidance of the operation of shipping lines, ports, fleets and marine transport enterprises and organizations [63, 72]. The communications system of the commercial fleet has a similar purpose [1, 41].

The ensurance of communications with vessels and ships over great distances has made it necessary to include in the communications system territorially separated PRTs's and PDRTs's, as well as switching and radio relaying centers making possible the rapid travel of large flows of information with the required automation of communications processes and units. In a modern communications system there must also be control centers for the purpose of monitoring the state of the entire system (or a specific region in global systems) and of controlling it with a change in information flows or the state of channels, when units go out of order, and the like.

For the purpose of organizing communications, ensuring it, and utilizing it in controlling forces, in a fleet there are communications agencies, which as a rule are communications departments or divisions which are headed by communications chiefs, to whom are subordinate communications units and subdivisions. The communications units and agency of an association, formation or shipping line are represented by the communications service, headed by a communications chief. The communications units of a fleet and the protecting subdivisions together with the fleet's communications administration (department) are represented by the fleet's communications service, headed by the fleet's

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communications chief. The fleet's communications service is a component of the VMF communications service. Heading it is the VMF chief of communications.

Thus, the communications service of the VMF and accordingly of the MMF and MRKh represents a very complex organism, whose multilateral activity is aimed at maintaining communications facilities and systems at the level of steadily increasing requirements, and at ensuring control under the complex conditions of fulfilling set goals in various regions of the global ocean.

Chapter 2. Features of Radio Wave Propagation at Sea and Calculations for Radio Communications Lines in Different Bands

2.1. Classification of Radio Waves and Electrical Characteristics of the Medium in Which They are Propagated

The band classification of radio waves and their classification according to their employment in marine communications are presented in Appendix 2.

In terms of method of propagation, radio waves are classified as freely propagated (direct), ground (surface), tropospheric and ionospheric (space). Characteristic of direct radio waves is propagation in free space (in a void) with the absence of any obstacles in their way (e.g., space radio communications). For such waves the effective value of the electric field strength of these radio waves, E_d (in mV/m), is determined by the following equation:

$$E_A = \frac{173\sqrt{P_1 D_1}}{r}, \tag{2.1}$$

where P_1 is the power of the transmitter emitted by the antenna, in kW; D_1 is the directivity factor of the transmitting antenna; and r is the distance between the points of transmission and reception of the radio waves, in km.

Ground radio waves are propagated directly above the surface of Earth. Because of the diffraction characteristic of VLF, LF and MF waves (whose wavelengths are commensurate with the dimensions of obstacles), the range of propagation of surface waves does not exceed 2000 km. Furthermore, they undergo absorption on account of penetration into Earth's strata and as a result of the consumption of energy in heat losses.

Tropospheric radio waves are propagated by means of scattering and reflection from various inhomogeneities of the troposphere (at an altitude on the order of 12 km) having different dielectric constants, whereby the main flow of energy travels through the troposphere. The propagation range of tropospheric waves does not exceed 1000 km.

Ionospheric (space) radio waves (longer than 10 m, and under certain conditions, VHF waves) are propagated on account of reflection from the upper half of the

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atmosphere-ionosphere (in the altitude range of 60 to 1000 km). The degree of atmospheric ionization is characterized by the electron concentration, N_e, the number of free electrons per 1 cm^3 (or 1 m^3). It has been proven experimentally that the distribution of electron concentration by altitude is in the form of a stepped curve, with a relatively smooth change in concentration from step to step.

In daytime are observed individual secondary maxima, which form regions (layers) at the following altitudes: D (60-90 km); E (100-120 km), F_1 (180-240 km) and F_2 (230-400 km). At night the process of recombination takes place (especially in dense layers of the atmosphere), as the result of which the D region disappears, and the F_1 region, which exists only during hours of illumination in the summmer, merges with F_2 into region F. Region F_2, unlike regions D, E and F_1, is unstable and subject to random changes.

In addition to these regulary existing regions of the ionosphere, from time to time a strong ionized "sporadic layer," E_s, forms, whose electron concentration surpasses the concentration of the E region as much as tenfold. Most frequently, at middle and equatorial latitudes it forms in the summer during the day, and in polar regions at night, independently of the season. The period of existence of the E_s layer is a few hours, and its length is a few dozen kilometers.

The outer shell of the ionosphere is a radial belt with a lower limit at the altitude of a few hundred kilometers above the Atlantic Ocean and an upper at an altitude of 1500 km above the Pacific Ocean. Space radio waves, because of reflection more than once from the ionosphere, are propagated around Earth at practically any distance. But just as is the case with surface and tropospheric radio waves, ionospheric waves are absorbed in penetration through the semiconducting ionized layers of the atmosphere.

Attenuation of a radio wave field because of losses in their propagation under real conditions is characterized by the attenuation factor, F, which is included as a cofactor in (2.1).

Radio waves are propagated in a semiconducting medium. Semiconductors are characterized by two parameters: dielectric constant, ε_d, in F/m, and conductivity, σ, in cm/m. Usually, instead of the absolute dielectric constant its relative value, ε, is used (a dimensionless magnitude). In the radio wave band these parameters are considered independent.

Under the effect of a variable electric field, in semiconductors bias currents, j_{sm}, and conduction currents, j_{pr}, arise, the ratios of which are expressed by the following equation:

$$\frac{j_{см}}{j_{пр}} = \frac{\varepsilon}{60\lambda\sigma}. \qquad (2.2)$$

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If $\varepsilon >> \lambda\sigma$, then the semiconducting mass (water, dry land) approaches a dielectric with respect to its properties, and when $\varepsilon << \lambda\sigma$, a conductor. For example, dry soil with respect to its properties approaches an ideal conductor for VLF waves, and an ideal dielectric for SHF waves.

The dielectric constant of the ionosphere depends on frequency, and is expressed by the equation:

$$\varepsilon = 1 - 80{,}8\frac{N_э}{f^2}, \tag{2.3}$$

where f is the frequency of the radio wave, in kHz.

It follows from equation (2.3) that at a certain frequency, called the plasma frequency, f_0 , the dielectric constant returns to zero. The value of f_0 can be found by solving the equation arrived at in terms of f :

$$f_0 = \sqrt{80{,}8N_э} = 9\sqrt{N_э}. \tag{2.4}$$

In [16] are formulated the following key properties of radio waves:

a) Both components of radio waves (the electric, E_z , and magnetic, H_y) are propagated at the same rate.

b) Between the electric and magnetic fields there takes place a phase shift in time and space, as the result of which the wavelength in a semiconducting medium (soil, water) is less than the wavelength in air.

c) Radio waves in a semiconducting medium are absorbed at a depth of h according to the exponential law $e^{-\delta h}$, and for media approaching conductors with respect to their properties, the absorption coefficient of a radio wave, δ , in 1/m, takes the form:

$$\delta = 2\pi\sqrt{\frac{30\sigma}{\lambda}}; \tag{2.5}$$

d) The absorption of radio waves is greater, the higher the conductivity of the medium and the shorter the wavelength.

The atmosphere in terms of its composition is inhomogeneous: In addition to electrons and ions, in it there are neutral molecules, in collision with which electrons give up part of the energy obtained from the propagated radio wave. Losses in its energy are caused by this. The dielectric constant and conductivity of an ionized gas are expressed by the equations:

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$$\varepsilon = 1 - 3190 \frac{N_э}{\omega^2 + \nu^2}; \tag{2.6}$$

$$\sigma = 2{,}82 \cdot 10^{-8} \frac{N_э \nu}{\omega^2 + \nu^2}, \tag{2.7}$$

where ν is the mean frequency of collisions between electrons and neutral molecules.

At high frequencies, when $\omega^2 >> \nu^2$, the electric parameters of the ionosphere depend on the frequency. The conductivity of the ionosphere is inversely proportional to the frequency, and, consequently, the absorption of the energy of radio waves in the ionosphere is reduced with an increase in frequency.

It follows from equations (2.6) and (2.7) that when $\nu = 0$ the conductivity disappears and the dielectric constant is determined from equation (2.3). Radio waves with frequencies less than f_0 cannot be propagated in an ionized gas, and the frequencies are reflected from the ionized layer. Since the electron concentration increases with altitude, the refractive index is reduced, the trajectory of the wave is turned with its convex side upward, and at its peak total internal reflection takes place. As a result of this the radio wave is turned back onto the semiconducting surface of Earth, from which it is again reflected in the direction of the ionosphere, etc. Of decisive importance for the reflection of a radio wave is the critical frequency, f_{kr}, of the F_2 layer, whose value depends on the time of day, the season and the phase of the 11-year period of solar activity.

Certain investigators (e.g., [3, 16]) have obtained equations relating the frequency to the maximum value of the electron concentration, $N_{e\ max}$, at the turning point of a specific layer with a specified angle of elevation:

$$f_{max} = \sqrt{\frac{80{,}8 N_{max}\left(1 + 2\frac{H}{a}\right)}{\sin^2\beta + 2\frac{H}{a}}}, \tag{2.8}$$

where a is the radius of Earth (a = 6370 km).

Its maximum value is reached by f_{max} when $\beta = 0$ (i.e., with mildly sloping rays):

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$$f_{\max 0} = \sqrt{\frac{80{,}8N_{\max}(a+2H)}{2H}}. \qquad (2.9)$$

With a vertically directed ray ($\beta = \pi/2$) equation (2.8) takes the form:

$$f_{кр} = \sqrt{80{,}8N_{\max}}. \qquad (2.10)$$

Consequently, the maximum applicable frequency (MPCh) for each region of the ionosphere is determined by the maximum electron concentration, the altitude of the region and the angle of elevation; frequencies of $f < f_{kr}$ are always reflected from the ionosphere regardless of the angle of elevation, and when $f_{kr} < f < f_{max}$, only with certain angles of elevation. In addition, frequencies of $f > f_{max}$ pass through the ionosphere and are not reflected from it. The MPCh's reflected from the ionosphere in slant sounding (the conditions for the reflection of which are more favorable than for vertically directed) exceed three- to four-fold the values of critical frequencies.

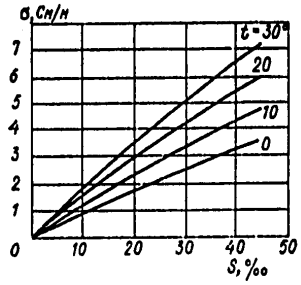

Figure 2.1. Conductivity of Sea Water as a Function of Its Salinity and Temperature

The propagation of radio waves is influenced also by the state of the semiconducting medium—Earth's surface, a considerable part of which (71 percent) is covered with water. Water and dry land are semiconductors in terms of their properties, but they are characterized by different values of ε and σ. The conductivity of sea water is non-identical and not constant, and depends on the salinity of the water and its temperature (fig 2.1). Different also is the dielectric constant in different regions of Earth, both of the global ocean and of dry land. The values of ε and σ for different kinds of surface on Earth are indicated in table 2.1. In the last column of this table are given the values of frequencies at which the density of the bias current equals the density of the conduction current.

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Table 2.1.

1) Поверхность	ε	σ, См/м	2) f, МГц, при ε = 60 λσ
3) Морская вода	80	4--5	900—1125
4) Пресная вода рек и озер	80	10^{-3} — 2,4·10^{-2}	0,225—2,25
5) Очень влажная почва	30	5·10^{-3} — 2·10^{-2}	3 12
6) Почва средней влажности	15	5·10^{-4} — 5·10^{-3}	0,6—6
7) Почва в Арктике	15	5·10^{-4}	0,6
8) Очень сухая почва	3	5·10^{-5} — 10^{-4}	0,3—0,6
9) Полярный лед	3	2,5·10^{-5}	0,15

Key:

1. Surface
2. f, MHz, with $\varepsilon = 60 \lambda\sigma$
3. Sea water
4. Fresh water of rivers and lakes
5. Very moist soil
6. Soil of medium moisture content
7. Soil in the Arctic
8. Very dry soil
9. Polar ice

In fig 2.2 a and b are reproduced charts of the conductivity of sea water in the global ocean in the summer and winter [37].

For the purpose of ensuring reliable radio communications, it is necessary that the signal's field strength, E_s, be greater than the noise level, E_p, which is characterized by the protection factor:

$$K_1 \geqslant \frac{E_c}{E_n}. \tag{2.11}$$

In Appendix 1 are given recommendations on taking into account factor K_1 [38, 59].

2.2. Features of Propagation, and Calculation of Radio Communications Lines

Very low frequency, low frequency (VLF and LF) and ultralow frequency (ULF) waves have properties much in common.

Radio waves in these bands are propagated as it were in a distinctive spherical waveguide, whose inside wall is represented by Earth's surface, and whose outside wall is represented by the lower limit of the D layer during daytime or the lower limit of the E layer at night. Both these layers are not

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absorbing layers for low frequencies and possess the properties of semiconducting media, which reflect VLF waves well and act as the conducting wall of the waveguide directing the radio wave radiation flux.

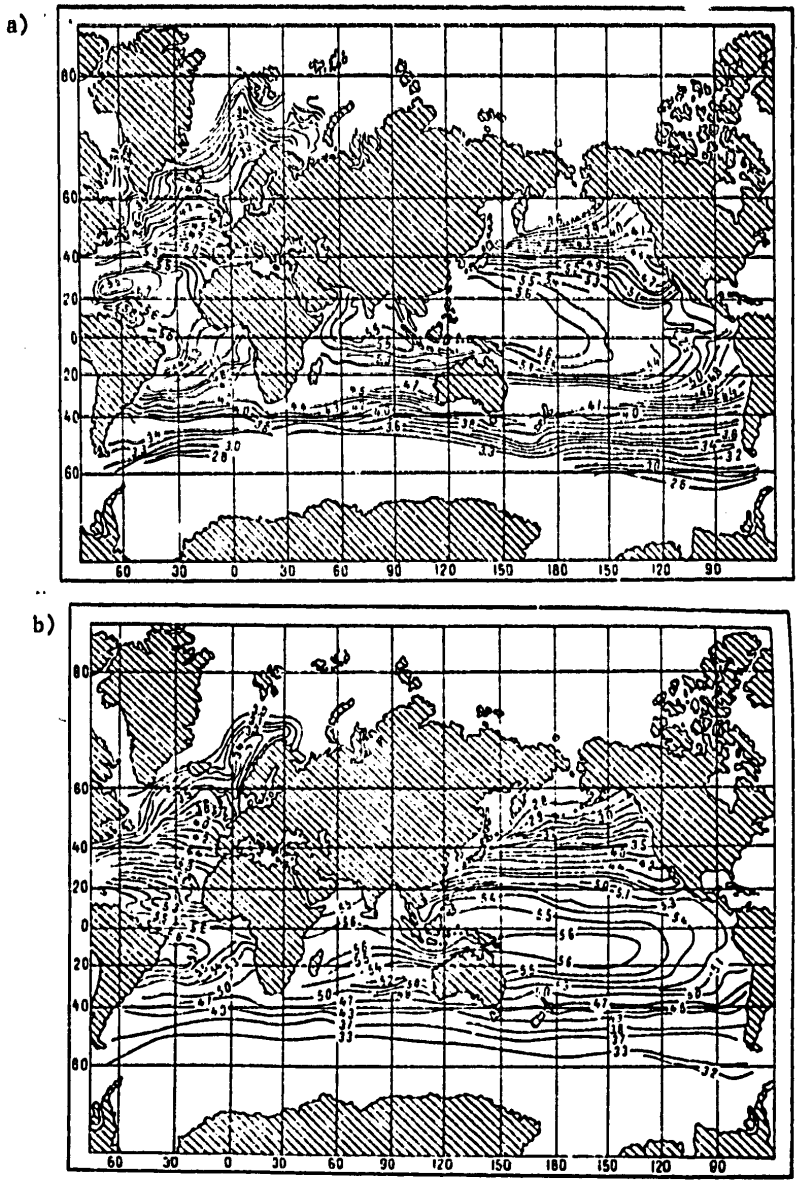

Figure 2.2. Conductivity of Sea Water in the Global Ocean: a--summer; b--winter

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The waveguide propagation diagram is shown in fig 2.3. The directing effect of this spherical waveguide makes it possible to observe the antipode effect, whereby at point C, opposite A ($r = \pi a \approx 2 \cdot 10^4$ km) radio waves converge, as at a focal point, and create an intensified field. With an increase in distance to 10^4 km, the strength of the field is reduced, and with a further increase in distance the rays begin to converge, which results in compensation of attentuation of the field because of losses in Earth and the ionosphere.

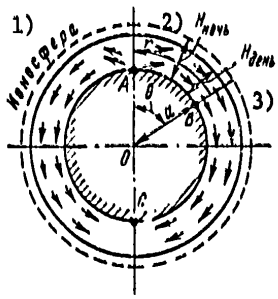

Figure 2.3. VLF Wave Propagation in the Earth-Ionosphere Spherical Waveguide

Key:
1. Ionosphere
2. H_{night}
3. H_{day}

For these reasons, in the Earth-ionosphere waveguide a family of waves is excited, and even near the transmitter is observed the interference nature of the structure of the field as a function of distance, caused by the superposition of these waves. At a distance of 2000 to 3000 km only a single intense wave of a purely waveguide nature remains.

This pattern for the waveguide process of the propagation of electromagnetic vibrations is completely characteristic of frequencies in the VLF band greater than 5 to 10 kHz, when the height of the waveguide, and especially communications ranges, are as a rule greater than the wavelengths employed. At frequencies below 2 to 3 kHz there is no waveguide process, and the process of the establishment of electromagnetic vibrations in the waveguide takes place. The lower base of the waveguide's cavity possesses the properties of a semiconductor, and the upper, of the ionosphere, depending on the time of day (in daytime, region D--a semiconductor; at night, region E--a dielectric).

A strict discussion of these processes is based on application of the theory of modes, which takes into account a great number of varying parameters and makes it possible by means of a computer to determine the amplitude and phase of the wave at the place of reception [2, 3].

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Since layers D and E come under the heading of stable ionospheric formations, VLF propagation is characterized by high constancy in the passage of long waves and in their rate of propagation, and is not accompanied by sudden changes in signal level. Random variations in field strength because of fluctuating changes in electron concentration are insignificant in terms of intensity (not greater than 10 to 30 percent) and take place very slowly (over dozens of minutes and even hours) and therefore are not recorded in the audio reception of signals. The 24-hour behavior of field strength along the path does not undergo marked changes. Sometimes sudden variations in the field are observed during the hours of sunrise and sunset.

Studies of recent years have demonstrated that although the walls of the waveguide are far from one another (about 2.5 λ for $f = 10$ kHz), nevertheless they are somewhat mobile because of a change during a 24-hour period in the altitude of the ionosphere (in the daytime region D is 72 to 80 km, and at night region E is about 90 km). This causes changes in the length of the path of radio waves, and, consequently, also regular 24-hour variations in the phase velocity of the signal, as well as seasonal variations, which influences the accuracy of radio navigation.

The annual variation in field strength is very slightly pronounced; in summer, during daylight hours, the field strength increases by 20 to 50 percent as compared with winter months. Ionospheric disturbances and variations in solar activity have but a slight influence on conditions for the propagation of radio waves in these bands.

Thus, the constancy of conditions for VLF wave propagation, their low dependence on ionospheric disturbances, their comparatively moderate absorption, their ability to penetrate water, and their insignificant vulnerability to the influence of nuclear explosions make it possible to receive signals from powerful VLF radio transmitters at practically any point on Earth. VLF waves are extensively employed in global communications and navigation systems, as well as for the purpose of transmitting signals to submerged submarines and of transmitting precise upper-class frequencies and standard time system signals.

On the other hand, the VLF band has some disadvantages, too, such as a comparatively high level of atmospheric and industrial interference, as well as of interference from neighboring radio stations, which necessitates the use of powerful transmitters; difficulty in the effective emission of electromagnetic high-power fields because of the small dimensions of antennas as compared with the wavelength, and the low radiation resistance and efficiency of antennas, which necessitates the employment of antennas of great size; the low throughput of communications channels because of the narrowness of the frequency band, which results in the need to use, as a rule, a telegraph mode, with relatively not too high operating speeds; and the difficulty of achieving narrow-beam radiation and reception.

The electric field strength at not too great distances from the transmitter (up to 1000 km) can be calculated on the basis of the assumption of the

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propagation of VLF waves in the form of ground waves on account of diffraction passage around Earth, from the three upper curves of the MKKR [International Radio Consultative Committee] graphs reproduced in fig 2.4 [38]. Graphs of $E_1 = f(r)$ are compared for 1 kW of radiated power with a directivity factor for the transmitting antenna of $D_1 = 1.5$. Then the field created by the transmitter, of power P in kW, at the point of reception is determined as follows:

$$E_A = E_{A1} \sqrt{P}; \tag{2.12}$$

$$P = P_0 \eta D_1, \tag{2.13}$$

where P_0 is the power supplied to the radio transmitter, in kW; and η is the efficiency of the antenna-feeder unit.

At great distances of r, in km, radio waves of wavelength λ, in km, are propagated as ionospheric waves in a spherical waveguide and in this case the electric field strength, in mV/m, is calculated from the semi-empirical Austin-Cohen equation:

$$E_A = \frac{300 \sqrt{P_1 D_1}}{r} \sqrt{\frac{\theta}{\sin \theta}} e^{-\frac{0.0015}{\lambda^{0.5}} r}, \tag{2.14}$$

where θ is the central angle between the points of radiation and reception (cf. fig 2.3), or from the Aspenshield, Andersen and Bailey equation:

$$E_A = \frac{300 \sqrt{P_1 D_1}}{r} \sqrt{\frac{\theta}{\sin \theta}} e^{-\frac{0.005}{\lambda^{1.25}} r}. \tag{2.15}$$

In equations (2.14) and (2.15) in an exponent of the $\exp(-ar/\lambda^m)$ type other factors are also assumed. For example, $(-0.0015r/\sqrt{\lambda})$ or $(-0.0045r/\lambda^{1.4})$, which were selected each time in order in the best manner to satisfy the variant of the experiments considered in the study [2, 3].

Distance r is related to central angle θ by the relationship $r = \theta a$ (cf. fig 2.3) and at small distances (up to $r = 1000$ km) $\sqrt{\theta/\sin \theta} \approx 1$, and as the distance increases the argument increases more rapidly than the sign, and with $r = 20{,}000$ km the value of $\sqrt{\theta/\sin \theta} \to \infty$, which characterizes the directional properties of the waveguide.

The Austin-Cohen equation gives acceptable results for calculations of E_d at distances from 1000 to 18,000 km. The $E_d = f(r)$ curve from calculated data for this equation is given in fig 2.5.

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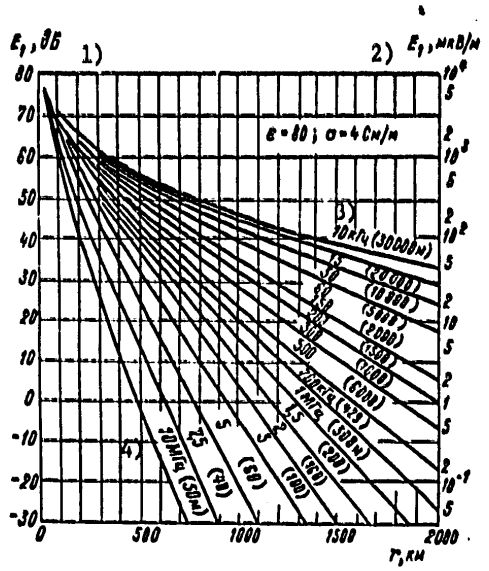

Figure 2.4. Curves for Propagation of a Ground Wave (Sea)

Key:

1. E_1, dB
2. E_1, μV/m
3. 10 kHz
4. 10 MHz

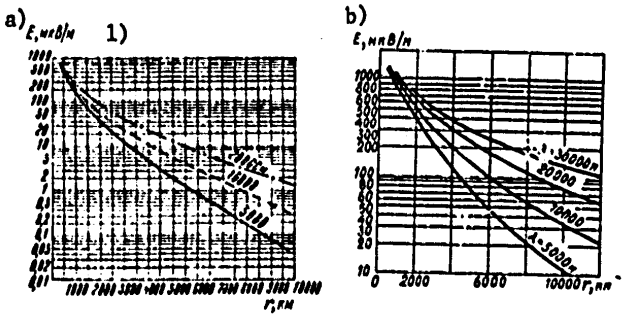

Figure 2.5. Graphs for Calculating Range of Radio Communications in the VLF Band: a--E_{d1} with P = 1 kW ; b--E_d with P_0 = = 1000 kW and η = 0.5

Key:

1. E, μV/m

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The conclusion from experiments is that the actual field strength is somewhat greater than the field strength calculated with equation (2.14). In addition, it has been confirmed that for the VLF band the principle of reciprocity for the source and observer is violated, especially at great ranges and on paths lying across Earth's magnetic field. For example, the mean values of the field strength measured along west-east lines (Hawaii to the Panama Canal Zone, r = 8450 km) were lowered in daytime by a factor of 10 to 12, and at night by a factor of 3.5. In the same experiments, along a north-south line (New York to Panama Canal Zone, r = 3820 km) with variation in the direction of propagation of the radio wave the field strength practically did not change. Data have been presented, to the effect that on paths located at equal latitudes the amplitude of the field is greater than on paths in a meridional direction [3].

As already stated, reception conditions are determined by the ratio of the signal's field strength to the noise level. In the VLF band a relatively high level of atmospheric noise is evidenced, created chiefly by lightning discharges, and its intensity depends on the frequency, the geographic location of the reception center, the season, the time of day, and the passband of the receiver. In fig 2.6 is given a graph of the expected level of atmospheric noise as a function of the area of reception, in the equatorial zone, 1, and at middle, 2, and northern, 3, latitudes in the Atlantic Ocean with a receiver passband of 20 Hz [37]. With other passbands, Δf^* , the noise level, E_p^* , is determined by the equation:

$$20 \lg E_n^* = 20 \lg E_n + \\ + 10 \lg \Delta f^* - 20 \tag{2.16}$$

or

$$E_n^* = E_n \sqrt{\frac{\Delta f^*}{\Delta f}}, \tag{2.17}$$

where Δf is the passband of the receiver for which the graph is calculated, in Hz, and E_p is the level of atmospheric noise, determined from the graph for specific conditions, in μV/m (dB).

From a comparison of levels of atmospheric noise in the VLF band over a continent and the ocean, it is obvious that in regions of an ocean, e.g., the Pacific, the noise level is 5 to 10 dB lower on average. If it is taken into account that the attenuation of VLF signals in propagation over the sea is less than over dry land, then the gain in the signal-to-noise ratio reaches 10 to 15 dB, because of which the effective range of VLF radio stations is increased by approximately a factor of 1.5, and with P_0 = 1000 kW reaches values of $(5 \text{ to } 7) \cdot 10^3$ km.

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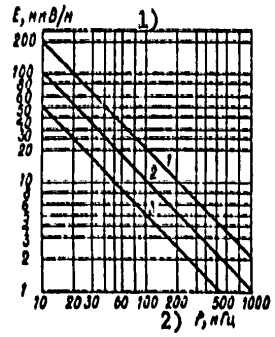

Figure 2.6. Levels of Atmospheric Noise

Key:
1. E, μV/m
2. P, kHz

VLF waves are propagated in a spherical waveguide, and therefore, as in any waveguide, it has its optimal frequencies which are propagated with the least attenuation. This can be judged also from equations (2.14) and (2.15), in which for a specified distance the wavelength is optimal.

Since reception conditions are determined by the ratio E_s/E_p, which varies in relation to the band, that wavelength will be optimal at which this ratio reaches a maximum.

Medium frequency waves (MF waves) cover the band from 300 kHz (1000 m) to 3 MHz (100 m) and are propagated during the day only as ground (surface) waves, and at night as ground and ionospheric waves. This feature of the propagation of MF waves is explained by the fact that in daytime there exists but a slightly ionized D layer, where the electron concentration, because of the great number of collisions (on the order of $5 \cdot 10^7$ 1/s) is insufficient for the reflection of MF waves. Therefore, in the D layer the heavy absorption of MF waves takes place and there is not enough energy for them to be able to pass through this layer and be reflected from the E layer, where the number of collisions is 10^5 1/s.

Thus, in the daytime hours MF waves are absorbed considerably, and this absorption increases as the wave becomes shorter. Radio communications with medium frequency waves are totally stable in the daytime when radio waves are propagated over the sea at a range of up to 1000 to 1500 km, and of up to 500 km over dry land.

With the onset of darkness the D layer vanishes and the absorption of the electromagnetic field of medium frequency waves is reduced considerably, and, since they are propagated as both ground and ionospheric waves on account of

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reflection from the E layer, then at the reception center the arrival of both radio waves is possible. This results in random fluctuations (fading) in the resultant field of the signal.

The intensity of fading increases with a shortening of wavelength and is most dramatically pronounced near the lower limit of MF waves (100 m), where the signal's field can vary by a factor of a few dozen, lasting from a second to a few dozen seconds.

Diurnal fluctuations in field strength at the reception point are considerable only at long distances, when with the onset of darkness ionospheric waves begin to be propagated. As a result of this, the level of the signal increases and MF waves can be propagated a distance of up to 4000 km. But in this case, because of the interference of radio waves (on account of the different number of their reflections from the ionosphere) fluctuations in the resultant field--fading--again arise.

MF waves are characterized by seasonal variations in field level, which is evidenced in intensification of the field in winter, especially in the daytime at northern latitudes. In addition, in the summer, as the result of frequent thunderstorm phenomena, the level of atmospheric noise increases, which results in the worsening of conditions for signal reception.

Ionospheric disturbances during the 11-year period of solar activity practically do not influence the propagation of MF waves.

A considerable influence on conditions for the propagation of ground waves is exerted by coastal sections in the MF waveband, since radio stations are not always located at the water line. As a result, radio waves propagated over the non-uniform surface experience different absorption.

The absorption of radio waves over a path r_1 and r_2 with electrically inhomogeneous surfaces, e.g., dry land (ε_1, σ_1) and the sea (ε_2, σ_2), is determined not only by the attenuation function, depending on the degree to which the path is occupied by dry land, which is determined by the equation

$$q = r_{\text{dry land}}/(r_{\text{dry land}} + r_{\text{sea}}) , \tag{2.18}$$

but also by the position on the path of the dry land section itself [76]. The main percentage of absorption occurs at sections which are contiguous with transmitting and receiving antennas.

For a path consisting of three sections, the field strength does not depend on the electrical parameters of the middle section, r_2 , and is determined only by the properties of the end sections.

If the end sections pass over dry land, then even with low strength ($q \approx 0.1$) the attenuation factor diminishes drastically, and over the sea, then the influence of the dry land is pronounced only with $q > 0.8$.

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MF waves have found extensive application both in marine communications and in navigation.

Methods of calculating the field strength are divided into the method of calculating the strength of surface waves (in daytime) and the method of calculating the strength of space waves (at night). For calculating the field strength of surface waves, MKKR graphs are used (cf. fig 2.4).

For the purpose of calculating the field strength (in μV/m) at night (space and surface waves), the empirical equation in [101] is used:

$$E_{\text{д}} = \frac{10\,233}{\sqrt{r}} \sqrt{PD}\, e^{-8{,}94\cdot 10^{-4}\lambda - 0{,}26r}. \tag{2.19}$$

High frequency (HF) waves cover the band from 100 to 10 m (3 to 30 MHz) and are propagated chiefly as ionospheric waves within the limits of Earth for any distance. In their propagation HF waves are absorbed by the D and E layers and are reflected from the F_2 layer. Reflection from the F_2 layer takes place because N_e in the E layer is approximately 20-fold lower than in the F_2 layer.

The absorption of HF waves occurs according to an exponential law with a factor of $e^{-\delta r}$, where δ is the absorption coefficient, and r is the distance traveled by the wave. In the HF waveband, $60\,\lambda\sigma \ll \varepsilon$ and $\omega^2 \gg \nu^2$ at the peak of the trajectory, and in a first approximation $\varepsilon \approx 1$. The absorption coefficient (1/m) can be determined from the equation in [3]:

$$\delta \approx 1{,}35\cdot 10^7 \frac{N_e \nu}{f^2}. \tag{2.20}$$

It can be concluded from equation (2.20) that the absorption coefficient for ionized gases is reduced with an increase in frequency. In addition, for a specified frequency the absorption coefficient is determined by the product $N_e\nu$, which is equal to 10^{17} for the E layer and 10^{15} for the F_2 layer. This makes it possible to disregard the absorption of radio waves in the F_2 region (it is 100-fold lower than in the E region). The HF waveband is limited with regard to the choice of frequencies for communications over a specified range with a definite path, since for the accomplishment of radio communications with HF waves it is necessary to fulfill simultaneously two conditions: $f_r \ll f_{\text{MPCh}}$ and $\delta < E_{d\,\text{dop}}$. The first condition limits the frequency band for communications from above, and the second from below.

For the purpose of enabling long-range communications, high frequency waves are reflected more than once from the F_2 layer in stages, whereby at each peak of a stage both conditions must be fulfilled.

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For HF wave communications over long distances different segments of bands can be used, depending on the time of day: during the day, 10 to 25 m; at night, 35 to 100 m; and at twilight, 25 to 35 m. The marine mobile service has been assigned segments in these bands.

Ionospheric disturbances, the appearance on the path of the sporadic E_s layer, and inconstancy of the F_2 layer are causes for the disruption of radio communications in the HF waveband.

The following are the main features of the propagation of HF waves: intense fading of signals, the existence of silent and echo zones, and the influence of the 11-year cycle of solar activity, geomagnetic disturbances and polar absorption.

The main reason for fading is the interference of waves reflected from the ionosphere, when at the point of reception the amplitude of the signal varies by a factor of dozens and hundreds, and the fading period varies from a few dozen seconds to tenths of a second.

The key method of combating fading is diversity reception (with respect to space, frequency, time, angle of arrival of the signal and its polarization). The most effective is space diversity with two or more antennas. For reliable reception the spacing of antennas must equal not less than 10 times the wavelength, with subsequent summation of the signal in the output of radio receivers. In the frequency band employed in the marine mobile service (f = = 4 to 27.5 MHz, λ = 11.0 to 75 m) the required distance between receiving antennas reaches 110 to 750 m. This method has found application on large vessels (by installing miniature ferrite receiving antennas on the vessel's bow and stern) and at coastal radio centers (long base-line diversity reception).

If frequency diversity is employed in addition to space diversity, then the reliability of reception is improved considerably.

The frequency diversity method has not yet become widespread on vessels of the maritime fleet, in view of the heavy utilization of the HF waveband and the need of having not less than two radio channels.

The time diversity method calls for the repetition of signals twice or more over uncorrelated time intervals (a few seconds) and is employed extensively for communications at sea, although the carrying capacity of channels is limited.

The method of diversity reception in relation to the angle of signal arrival is used in the microwave band, and the polarization diversity method in communications by means of the ionospheric reflection of radio waves, when the reception of signals is accomplished with antennas spaced vertically and horizontally. The latter method is simple and can be used on vessels.

In the propagation of HF waves beyond the limits of a ground wave, silent zones occur, where the reception of signals is hampered. It is possible to

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avoid a correspondent's happening upon a silent zone only if its steady position is known and if the frequency is selected properly.

Also included among features of HF wave propagation are radio echo phenomena, which can be short-range and long-range (round the world).

The means of combating a short-range echo are the employment of operating frequencies close to the MPCh, and the utilization of pencil-beam transmitting and receiving antennas with a directivity diagram pinned down.

A round-the-world echo can be forward and backward. A round-the-world echo disrupts all kinds of radio communications. For combating a forward round-the-world echo it is sufficient to employ pencil-beam antennas. A backward echo can be combated only by changing to lower frequencies.

Eleven-year cycles of solar activity improve conditions for the propagation of HF waves, since during these cycles the N_e of ionized regions increases, especially of F_2 regions, because of which MPCh's increase and absorption in the E and D layers is reduced.

Conditions for the propagation of HF waves worsen with different geomagnetic disturbances. A major role in the development of magnetic storms is played by radiation fields of Earth, which usually represent as it were magnetic catchers for streams of charged particles. Under the influence of magnetic disturbances these catchers open slightly and charged particles previously stored are in addition ejected into the ionosphere. As a result there is a sudden reduction in the concentration of the F_2 layer, which acquires a multi-layered configuration, the absorption of radio waves increases suddenly, and the MPCh is lowered in keeping with equation (2.8). In a number of similar cases the F_2 region at high latitudes loses its ability to reflect HF waves and communications are disrupted (from a few hours to two 24-hour periods).

A dependence has been observed, of solar activity on geomagnetic disturbances, as well as the recurrence of ionospheric disturbances every 27 days (the cycle for rotation of the sun on its own axis). Systematic observations of the sun have made it possible to predict beforehand ionospheric disturbances, for the purpose of combating which, at latitudes above 50°, more powerful transmitters are used, as well as directional antennas, changing to lower frequencies, and the employment of radio relay equipment and paths outside the disturbance zone.

At polar latitudes it is necessary to take into account the influence on HF wave propagation of absorption of a local nature. For example, in the polar aurora zone, which runs in a spiral at a geomagnetic latitude of 60 to 74°, there takes place the heavy absorption of radio waves for 2 to 3 h, which is often repeated for a few 24-hour periods. In a circular polar region with its center at the geomagnetic poles and its lower limit at a geomagnetic latitude of 64°, radio waves are absorbed for a few dozen hours (three to four 24-hour periods on average, and sometimes as long as 15). As the result of

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sudden ionospheric disturbances caused by solar flares, the D region is heavily ionized, absorbing HF waves from a few minutes to 1 or 2 h.

HF waves have found extensive application for communications with vessels at sea, since they make it possible to establish and maintain two-way communications with them at any point in the global ocean. But HF-wave radio communications with maritime vessels is difficult, which is accounted for by the mobility of these objects and the impossibility of using high-power transmitters and high-efficiency antennas on craft. Under these conditions of primary importance is the proper selection of HF-wave communications frequencies assigned by radio communications regulations for the maritime mobile service, as well as taking into account the features of the propagation of these waves in relation to specific areas of navigation, and the location of radio communications centers.

In the calculation of HF-wave communications lines, the most important thing is to select the frequencies most advantageous for communications. This is carried out in two steps: making a determination of the 24-hour variation in the MPCh and the 24-hour variation in the least usable frequencies (NPCh's); or making a calculation of the electric field strength at the point of reception.

There are several methods of calculating the MPCh. The most simple and convenient of them is the utilization of longterm IZMIRAN [USSR Academy of Sciences Institute of Terrestrial Magnetism, the Ionosphere and Radio Wave Propagation] forecasts, on which is based the calculation procedure used by A.N. Kazantsev. The procedure for calculating the MPCh includes the determination of path parameters (length of the path, number of discontinuities, coordinates of points of reflection from the ionosphere or of check points, and of points of entry into the absorbing layer in communications at high latitudes), for which are used a map of the world and a "great circle map."

In determining the MPCh, it is recommended that all layers of the ionosphere be taken into account and that for each hour the highest of the MPCh's for different layers be selected.

The optimal operating frequencies (ORCh's) generally equal 0.7 to 0.8 times the MPCh and represent the upper limit of the operating frequency band. The statistical processing of observation data has demonstrated that with a calm state of the ionosphere communications can be carried out 90 percent of the time at frequencies which on average are 15 percent below the MPCh, and for the E layer, at frequencies equal to the MPCh [26].

Since the critical frequencies of the F_2 layer have definite variations in the course of a 24-hour period, depending on the time of year, and, during a cycle of solar activity, depending on the latitude (the greatest variation is at high latitudes, where ORCh's can be as much as 40 percent below the MPCh, and the smallest is at middle latitudes in daytime), then operating frequencies can be chosen on the basis of the ratio $f_{\text{rab [operating]}}/f_{\text{MPCh}}$.

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With $f_{rab}/f_{MPCh} = 1$, communications will be ensured 50 percent of the time. Studies have shown that when $f_{rab}/f_{MPCh} = 0.8$ the probability of the occurrence of error is the lowest. It must also be kept in mind that in HF-wave communications the best communications quality is achieved with the variant of a minimum number of discontinuities. Depending on the length of the path, the minimum number of discontinuities is observed with the following values of the f_{rab}/f_{MPCh} ratio: 3000 km--0.85; 4000 km--0.78; and 6000 km--0.82, which can be used as the basis in determining ORCh's.

The second condition limits the range of possible operating frequencies from below, since the ionosphere is a semiconducting medium for HF waves, the absorption of HF waves in the ionosphere is increased at lower frequencies, and the electric field strength diminishes according to an exponential law:

$$E = E_0 e^{-\delta r}, \tag{2.21}$$

where E_0 is the electric field strength without taking into account losses in the ionosphere.

There are several semi-empirical methods of calculating the field strength for HF waves. The most widespread in our country has become A.N. Kazantsev's method, which has formed the basis of calculation instructions [12, 80].

For the purpose of calculation there is a set of charts of the space-time distribution of $f_{kr\ E}$ for various months and different levels of solar activity.

In addition, in calculating the NPCh it is necessary to know the minimum required field strength, E_{min}, for certain reception, which is determined by the noise level at the point of reception, as well as by the signal-to-noise ratio for a specific type of operation (cf. Appendix 1). In the HF waveband the noise level depends chiefly on interfering stations, which is occasioned by the high saturation of the band with radio stations and by the considerable length of radio communications lines. The noise level of stations increases from day to night and from summer to winter and reaches the highest values in the 5 to 7 MHz band in the winter at night, and the lowest in the summer during the day at frequencies of 17 to 20 MHz. If at the reception point noise from foreign stations predominates, then it is possible to employ approximately a median value of $E_{p.m}$ = 10 to 12 dB/μV [26].

After the calculation of frequencies, it is recommended that a graph be drawn of the 24-hour variation in frequencies, and from it a communications schedule. On the graph presented in fig 2.7 are entered 24-hour variations in the MPCh and NPCh, calculated for the following conditions: winter, January 1975; solar activity, W = 20; middle latitude path; length of discontinuity, 2000 km; transmission point--vessel with coordinates of ϕ = = 67°50' latitude north, λ = 3°12'0 longitude east; power supplied to

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antenna, P = 1 kW ; antenna, whip type; type of operation, BPCh [intermediate frequency unit]; reception points (shore)--dual reception with type BS2 21/3 200/4,5 antennas in Murmansk and Moscow. It is obvious from this graph that during reception in Murmansk (solid lines), for a transmitter with P = 1 kW , the NPCh line almost always passes above the MPCh, and under these conditions communications are impossible. By increasing the power of the marine transmitter to 5 and 15 kW it is possible to lower the NPCh, but it is not possible to ensure steady communications. The only acceptable solution is to carry out radio communications through another radio center--Moscow (dotted lines), i.e., the reception of messages from craft must be arranged for in relation to the areas in which they are sailing, not with just the single radio center of the port of assignment or the point of destination, but with several radio centers distributed across the country.

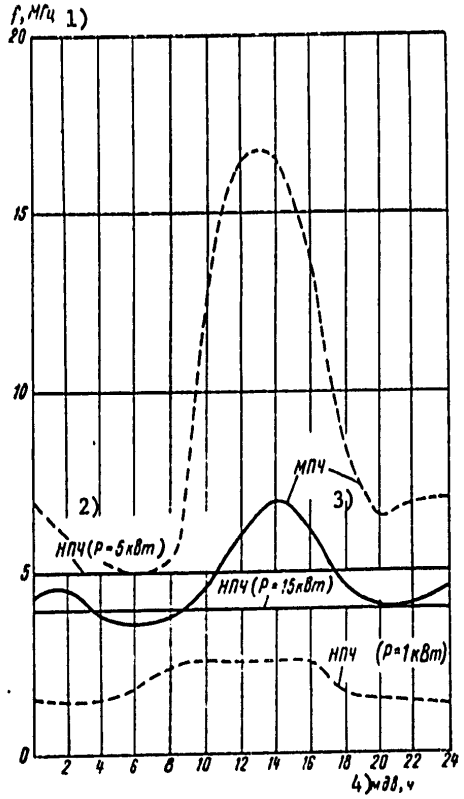

Figure 2.7. Range of Operating Frequencies for Ship-to-Murmansk and Ship-to-Moscow Radio Paths

Key:

1. f, MHz
2. NPCh
3. MPCh
4. Local time, h

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It is obvious from these graphs that the determination of optimal operating frequencies for communications with craft at sea (on the ocean) is a complicated task, and that communications frequencies cannot be universal, but must be designated separately in relation to communications with specific radio centers.

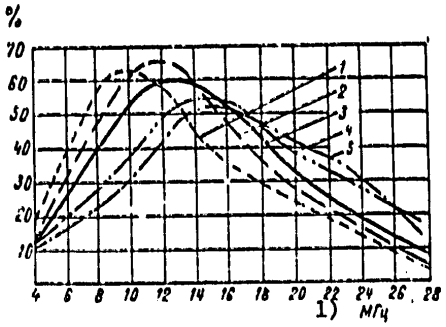

Figure 2.8. Travel of Radio Waves in Communications with MMF Radio Centers: 1--Murmansk; 2--Leningrad; 3--Moscow; 4--Odessa; 5--Vladivostok

Key:
1. MHz

Being confined to certain parameters and averaging data on the travel of radio waves during half of a solar cycle, in [40] the authors have presented averaged curves for the travel of radio waves in communications between craft and key MMF radio centers (fig 2.8) along paths more than 1500 km long, which are characterized by the heaviest transport vessel traffic. An analysis of these graphs demonstrates that for each radio center there exists its own range of optimal frequencies: Murmansk--8 to 12 MHz; Leningrad--10 to 14 MHz; Moscow--10.7 to 15 MHz; Odessa--13 to 17 MHz; Vladivostok--13.2 to 17.8 MHz [40].

Since the absorption of HF waves is proportional to $[N_e, \nu]$ in (2.20) and is reduced with an increase in f, then in equatorial regions, where N_e is greater, radio waves are absorbed more intensely, and, consequently, communications with craft in these regions takes place under more severe conditions.

In calculating optimal operating frequencies for marine paths, it is necessary to take into account the fact that sea vessels are mobile objects, and therefore the bearings and distances between the vessel and radio center change. These changes are not of importance for the duration of a single radio communications session, but over the days of a crossing MPCh's can change considerably. Therefore, the operating frequencies for marine communications must not be strictly regulated, but they must be chosen on the basis of regions of navigation and the intensity of illumination of the route. Equatorial, arctic and antarctic regions must be especially singled out.

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Numerous experimental data and calculations have demonstrated that on long-range marine paths it is advisable to use as the ORCh the maximum possible upper frequency limit as the result of which the absorption of radio waves along the path is reduced severalfold. Besides, in this section of the band there is the lowest level of atmospheric noise and the highest frequency capacity, and it is also possible to use more effective miniature antennas.

Ultrashort waves (UKV's) [very high frequency (VHF), ultrahigh frequency (UHF) and superhigh frequency (SHF) waves] cover the range from 1 cm to 10 m. Waves in this band are slightly diffracted around the surface of Earth. For this reason the range (in km) of their propagation as ground waves only to a slight degree surpasses the range of direct visibility and is calculated, for conditions of normal atmospheric refraction, from the graph presented in fig 2.9, or by the equation:

$$r = 4{,}12\,(\sqrt{H_1} + \sqrt{H_2}), \tag{2.22}$$

where H_1 and H_2 are the heights of the transmitting and receiving antennas in meters.

The effective value of the resultant field strength of VHF waves (in mV/m) as the result of the interference of direct and reflected rays is determined by B.A. Vedenskiy's "square law" equation:

$$E_A = \frac{2{,}18\sqrt{PD}\,H_1'H_2'}{r^2\lambda}, \tag{2.23}$$

where H_1' and H_2' are "normalized antenna heights," which are lower than the geometrical and represent the heights of the antennas above the plane tangent to Earth's surface.

Equation (2.23) is used for distances of $r > 18H/\lambda$, and from it it follows that shortening of the wavelength and increasing the heights of the antennas' location results in an increase in the strength of the resultant field at the point of reception.

In the propagation of ultrashort waves within the range of direct visibility the fading of signals is possible, the reason for which is the change over time in the refraction of radio waves. With negative refraction there occurs a shortening of ranges of direct visibility, as the result of which the second radio station turns out to be in a shadow region. With positive refraction, the difference in the path of the direct and reflected rays is altered, which results in a reduction in the signal's field.

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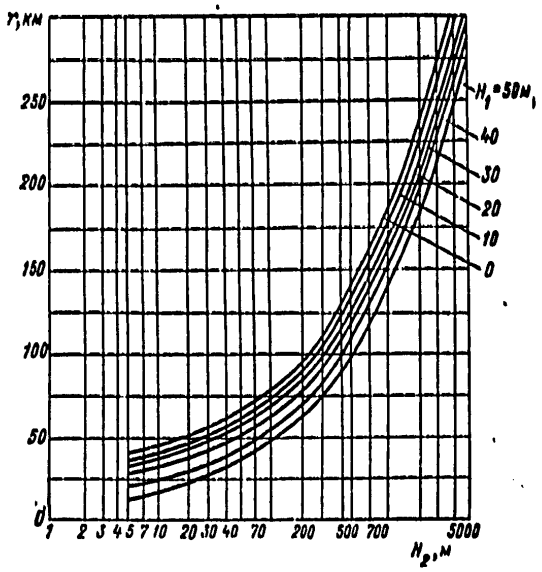

Figure 2.9. Graph for Calculating Range of Radio Communications in the Ultrashort Waveband

Ultrashort waves are propagated not only as ground waves, but also as waves reflected from regular regions of the ionosphere during years of high solar activity, and of scattering in the troposphere and ionosphere, and from ionized meteor trails.

For stable communications in these cases high powers and cumbersome pencil-beam antennas are required, which are difficult to employ under conditions aboard ship; therefore, they are not discussed here. It is more promising on craft to employ artificial Earth satellites (AES's) as radio relayers for UKV signals.

In considering satellite communications lines from the energy point of view, it must be kept in mind that the power of the transmitter in the AES and the dimensions of antennas in satellites and on vessels are restricted, paths are very long, and different kinds of noise and interference influence the receiver, in addition to the useful signal.

Equations for communications with active radio relaying on board an AES have the following form [77]:

In the Earth-AES section

$$P_1 = \frac{16\pi^2 r_1^2 F_1 P_{ш2}}{\lambda_1^2 D_1 D_2 \eta_1 \eta_2} \left(\frac{P_c}{P_ш}\right)_{вх2}; \qquad (2.24)$$

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and in the AES-Earth section

$$P_{s} = \frac{16\pi^2 r_2^2 F_2 P_{ш1}}{\lambda_2^2 D_1 D_2 \eta_1 \eta_2} \left(\frac{P_c}{P_ш}\right)_{вх1},$$

(2.25)

where P_1 and P_2 are the effective power radiated by the transmitting antennas on Earth and the AES; r_1 and r_2 are the communications ranges; F_1 and F_2 are attenuation factors caused by attenuation of the signal's energy; D_1 and D_2 are the gain of the transmitting and receiving antennas; η_1 and η_2 are the power transmission coefficients of the antenna-waveguide circuits of the transmitter and receiver; $P_{ш1}$ and $P_{ш2}$ are the noise power at the input of receivers on Earth and in the ISZ; and $(P_c/P_ш)_{вх1}$ and $(P_c/P_ш)_{вх2}$ are the minimum permissible signal-to-noise ratio of receivers on Earth and in the AES.

The noise power (in W) at the input of a receiver is calculated by the equation:

$$P_ш = kT_\Sigma \Delta f,$$

(2.26)

where $k = 1.38 \cdot 10^{-23}$ W/Hz·deg is the Boltzmann constant; T_Σ is the equivalent noise temperature of the receiving antenna (taking into account intrinsic and extrinsic noise); and Δf is the passband of the receiver, in Hz.

In carrying out communications by means of AES 's, radio waves pass twice through Earth's atmosphere, which considerably reduces the level of the signal's power at the point of reception. These losses are caused by the absorption of radio waves in gases and water vapor in the atmosphere. All kinds of losses in Earth's atmosphere (with the exception of heavy rainfall) can be disregarded in the 3 to 6 GHz band [90]. At frequencies below 3 GHz a major role is played by polarization losses (at $f = 1$ GHz losses equal 5 to 7 dB), and at frequencies of about 10 GHz losses in atmospheric gases reach 10 dB. The noise level is low in the UHF and SHF wavebands. In addition, it must be kept in mind that in communications by means of AES 's radio waves undergo refraction (it influences the accuracy of the operation of homing systems), absorption in the troposphere and fading of an interference nature (to eliminate this, the elevation angle of an antenna should be 5 to 7°), the Doppler effect (in movement of the AES relative to the station), and the influence in the input of receivers of noise of different origin (cosmic, atmospheric, ground surface, etc.). As a result, on paths of great length (with an orbit altitude of 35,000 km the communications range between end points is 40,900 km), attenuation of the signal can reach 200 dB [77]. On the other hand, calculations have demonstrated that when cooled parametric amplifiers are used ($T_\Sigma = 100$ K) the signal is tenfold

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stronger than the noise, which is totally sufficient for enabling any kind of radio communications by means of AES's [62]. For an approximate estimate of the parameters of a satellite communications line, it is possible to employ the nomogram in fig 2.10 [77].

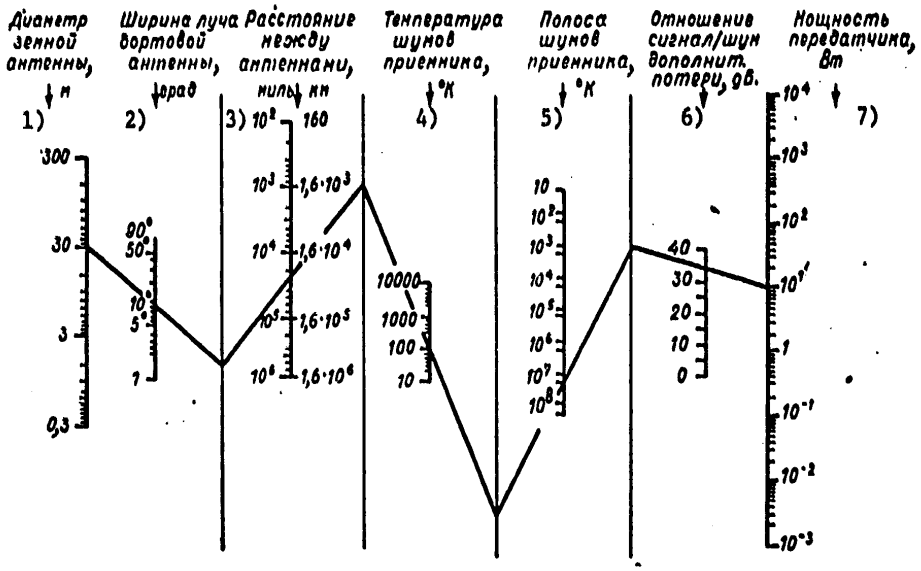

Figure 2.10. Nomogram for Calculating Communications Lines with AES's

Key:

1. Diameter of ground antenna, m
2. Beam width of airborne antenna, degrees
3. Distance between antennas, miles, km
4. Noise temperature of receiver, °K
5. Noise band of receiver, °K
6. Signal-to-noise ratio of additional loss, dB
7. Power of transmitter, W

The following frequency segments have been assigned to marine satellite communications: for transmission to AES's--157.31 to 157.41 MHz and for transmission from AES's--161.91 to 162.01 MHz, and for the marine mobile service--1535 to 1542.5 and 1636.5 to 1644 MHz [43, 48, 51].

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Radio relaying of signals from on board an AES to another point of Earth can be accomplished at once or with a delay (storage) of the signal and relaying of it by the satellite.

AES's can travel in a plane passing through the center of Earth in elliptical and circular orbits, which are divided in turn according to angle of inclination into polar orbits, if the angle of inclination is 90°, oblique orbits, if the angle of inclination is greater than 0° but less than 90°, and equatorial, if the angle of inclination equals 0°. The angle of inclination of the orbit is read from the equator and influences the area covered by the AES.

Orbits are characterized by apogee and perigee. With regard to altitude, orbits are low (150 to 5000 km) with a short cycle of rotation (1 to 3 h) and high (more than 5000 km) with a long cycle of rotation. In particular, an equatorial round orbit at an altitude of H = 35,810 km with a 24-hour cycle of rotation is called a stationary orbit, if the AES travels in the direction of Earth's rotation from west to east. Such an AES is stationary in relation to the communications center on Earth, since its angular velocity equals the angular velocity of the rotation of Earth on its own axis. This orbit is distinguished by high stability. Three stationary AES's positioned at an interval of 120° make possible "exposure" of 98 percent of the area of Earth, with the exception of not too large areas around the poles (fig 2.11 а).

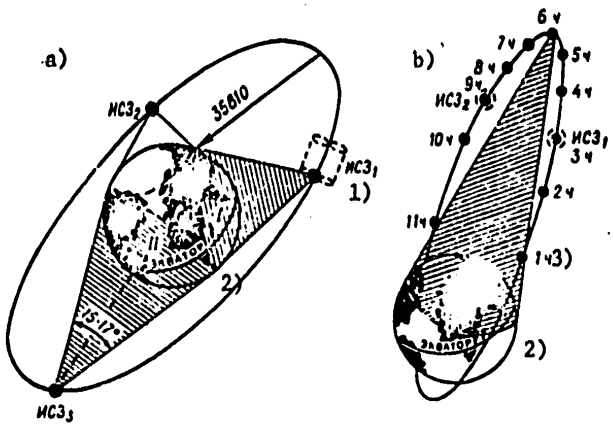

Figure 2.11. Utilization of AES's for Communications: а--in stationary orbit; б--in elliptical orbit

Key:
1. AES_1
2. Equator
3. 1 h

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When it is necessary to provide northern regions with communications, it is necessary to bring a set of two more AES's into oblique elliptical orbits (fig 2.11 b). It can be calculated so that an AES will be at the apogee in the daytime in areas most heavily navigated, and at the perigee at night over areas with the least navigation, which enables communications at the apogee for the greater part of a 24-hour period.

In selecting orbits it is necessary to pay attention to the range of communications and its extensiveness. The extensiveness of communications can be determined (fig 2.12) by the following equation:

$$L = 2a\theta = 2R\left[\frac{\pi}{2} - \beta - \arcsin\left(\frac{a}{a+H}\cos\beta\right)\right], \tag{2.27}$$

where a is the radius of Earth.

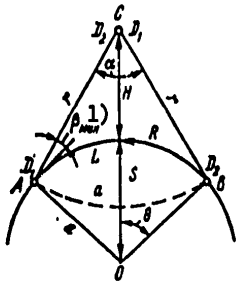

Figure 2.12. Pattern of Radio Coverage from an AES

Key:
1. β_{min}

The maximum slant range equals

$$r = \sin\theta\frac{a+H}{\cos\beta}, \tag{2.28}$$

and the radius of the circle covered is determined by the angle

$$R = a\theta, \tag{2.29}$$

$$\theta = \left[\arccos\left(\frac{a}{a+H}\cos\beta\right)\right] - \beta. \tag{2.30}$$

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The area of the surface of Earth exposed to a single AES can be calculated by the equation:

$$S = 2\pi a^2\left(1 - \cos\frac{\theta}{2}\right), \tag{2.31}$$

and the percentage of this area in terms of the entire surface of Earth equals

$$\frac{S}{S_0} = \frac{1 - \cos\frac{\theta}{2}}{2} \tag{2.32}$$

or

$$\frac{S}{S_0} = \frac{S}{4\pi a^2}, \%. \tag{2.33}$$

Theoretically calculated ranges and extensiveness for radio communications by means of AES's are presented in fig 2.13.

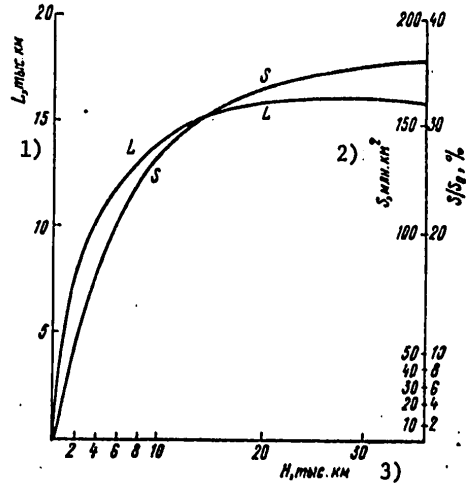

Figure 2.13. Range and Extensiveness of Radio Communications by Means of AES's

[Key on following page]

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Key:
1. L, thousand km
2. S, million km^2
3. H, thousand km

The duration of communications depends on the ascent and approach of the AES at a given point. With an increase in altitude of the AES the duration of the AES's coverage, and, consequently, of communications, increases, but non-identically, as a function of the polar or equatorial orbit chosen. In a polar orbit the influence of the AES's altitude is exceedingly substantial at all altitudes up to 8000 km, and a further increase in altitude results in a less pronounced gain in the duration of communications. For example, with the altitude of an AES's orbit at 1930, 7350 and 30,000 km the communications period equals respectively 10 min, 2 h and 9.5 h.

If the communications centers are located on both sides of the equator, then polar orbits are not optimal. An AES in equatorial orbit will enable more frequent periods of reciprocal coverage because of the movement of these centers when Earth rotates on its axis in the same direction in which the satellite is traveling. Furthermore, the period of coverage of the AES at the equator is longer, the higher the altitude of the AES. With oblique orbits the duration of coverage of an AES is of an intermediate value between its duration of coverage with polar and equatorial orbits.

A distinctive feature of satellite communications lines of great length is the considerable time for propagation of the signal, which is noticeable in telephone conversations. For example, for a line with stationary and elliptical orbits (H = 36,000 to 40,000 km), the average delay time reaches 300 ms, which is permissible.

For the purpose of enabling satellite communications with vessels, of greatest interest are AES's put into stationary orbits. For example, in the "Inmarsat" international satellite marine communications system (with the participation of socialist countries, i.e., the USSR, PNR [Polish People's Republic], GDR, NRB [People's Republic of Bulgaria] and Cuba), three AES's will be put into synchronous geostationary orbits over the Indian, Pacific and Atlantic oceans, which will make it possible to provide with stable communications all areas of the global ocean from 70° latitude north to 70° latitude south.

Chapter 3. Features of Communications with Submarines and Deepwater Instruments

3.1. Features of Propagation and Calculation of VLF and ULF Communications Lines with Submarines and Deepwater Instruments in the Submerged Position

Communications with submarines in the submerged position by employing a very low frequency (VLF) or ultralow frequency (ULF) radio communications transmitter is illustrated diagrammatically in fig 3.1. The VLF (ULF) radio transmitter, 3, is remote controlled from the control center, 1, through intercenter communications and keying lines, 2. Signals are transmitted by means of

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electromagnetic waves, 4, which are propagated between the ionosphere, 5, and the surface of the ocean, 6. The path of the electromagnetic wave from the transmitter on the shore and to the submarine, 7, submerged in the water can be divided into two sections: in an air medium to the area of submersion at a distance of r , and in water, from the surface of the water to the receiving antenna at a depth of h .

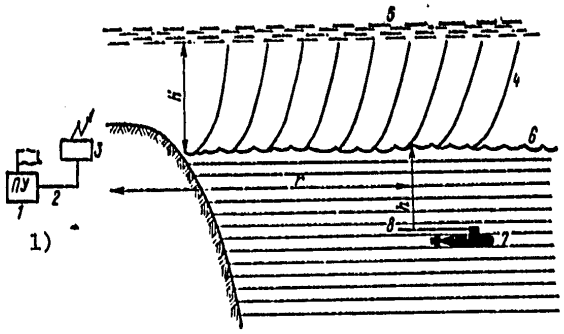

Figure 3.1. Operating Principle of VLF or ULF System for Radio Communications with Submarines in the Submerged Position

Key:
1. PU [transmitter]

According to Shchukin and Leontovich, conditions at the interface of the two media (air-water) are determined by the equation:

$$\sqrt{\varepsilon^2+(60\lambda\sigma)^2}\gg 1. \qquad (3.1)$$

The ratio between the horizontal components of the strength of the electric and magnetic fields at the interface in the first medium (in air, 1) is determined by the parameters of the second medium (in water, 2). Radio waves originating in the second medium represent plane waves, which are propagated into the depth of the medium in the direction of the normal to the interface, and experience absorption, governed by the parameters of the second medium.

Because of the conductivity of water, in the propagation of radio waves along the surface of Earth a dip in the wave front occurs, i.e., the horizontal component of the electric field. At the interface of the two media the vertical and horizontal components of the electric field (W/m) are determined on the basis of the equation:

$$E_{1z}=\frac{E_{1r}}{j\varepsilon_{\kappa}} \quad ; \quad z=0, \qquad (3.2)$$

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and of the magnetic field (A/m) from the equation:

$$H_{1y} = -\frac{\sqrt{\varepsilon_k}}{120\pi} E_{1x} \quad ; \quad z = 0, \tag{3.3}$$

where ε_k is the relative complex dielectric constant, where

$$\varepsilon_k = \varepsilon - i \cdot 60\lambda\sigma. \tag{3.4}$$

For the sea (with $\varepsilon = 80$ and $\sigma = 3$ to 6 cm/m), in the radio band $\varepsilon_k = 2.4 \cdot 10^6$ to $2.5 \cdot 10^2$ and, consequently, boundary condition (3.1) is fulfilled right down to the shortest wavelengths.

Components E_{1z} and H_{1y} are related as follows:

$$H_{1y} = \frac{E_{1z}}{120\pi} \quad ; \quad z = 0. \tag{3.5}$$

In the transfer of radio waves from the air into the water the magnetic field strength does not change. Excluding H_{1y} from equations (3.3) and (3.5) and substituting in equation (3.2) ε_k in (3.4), we find:

$$E_{1x} = \frac{E_{1z}}{\sqrt{\varepsilon - i \cdot 60\sigma\lambda}}. \tag{3.6}$$

If the numerator in equation (3.6) is substituted in the form of the absolute value of the phase factor, we get in expanded form:

$$E_{1x} = \frac{E_{1z}}{\sqrt[4]{\varepsilon^2 + (60\lambda\sigma)^2}} e^{i\left(\omega t + \frac{\alpha}{2}\right)}, \tag{3.7}$$

where

$$\alpha = \operatorname{arctg} \frac{60\lambda\sigma}{\varepsilon}. \tag{3.8}$$

Directly above the surface of the water the vertical and horizontal components are expressed by the equations:

$$E_{1x} = \frac{E_{1z}}{\sqrt[4]{\varepsilon^2 + (60\lambda\sigma)^2}} e^{i(\omega t + \alpha)}. \tag{3.9}$$

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Since σ = 3 to 6 cm/m , ε = 80 and λ > 20,000 to 30,000 m , then the second term in the radicand is much greater than the first, and therefore the equation is simplified, taking the form:

$$E_{2z} = \frac{E_{1z}}{\sqrt{60\lambda\sigma}}; \tag{3.10}$$

$$E_{2x} = E_{1x} = \frac{E_{1z}}{\sqrt{60\lambda\sigma}}; \tag{3.11}$$

$$\frac{E_{1z}}{E_{2x}} = \sqrt{60\lambda\sigma} \tag{3.12}$$

Since with the correctness of the conditions in (3.1) the radicand in equations (3.7) and (3.9), $\varepsilon^2 + (60\lambda\sigma)^2$, is much greater than unity, then in air E_{1z} is always $\sqrt[4]{\varepsilon^2 + (60\lambda\sigma)^2}$ times greater than E_{1x} . Thus, with λ = 30,000 km , δ = 4 cm/c and ε = 20 , E_{1z} = 2700 E_{1x} , and in sea water E_{2x} = 2700 E_{2z} . Therefore, it is advisable to receive VLF (ULF) signals in air with vertical antennas, and with horizontal antennas in sea water. In a loop antenna reacting to the magnetic field of a radio wave signals of the same amplitude will be induced regardless of its position in the air or water.

Of special importance is the feasible depth of the underwater radio receiver, h . The Shchukin-Leontovich boundary condition makes it possible to calculate it at a depth from a known value of the field strength above the surface of the water, by reducing by the absorption coefficient, δ , computed on the assumption of the propagation of electromagnetic waves in a homogeneous medium with the parameters of the sea.

Knowing the value of the field strength above the water, from the equations given below it is possible to determine the horizontal and vertical components under water:

$$E_{2x} = \frac{E_{1x}e^{-\delta h}}{\sqrt[4]{\varepsilon^2 + (60\lambda\sigma)^2}} e^{i\left[\omega\left(t - \frac{h}{v}\right) + \frac{\alpha}{2}\right]}; \tag{3.13}$$

$$E_{1z} = \frac{E_{1z}e^{-\delta h}}{\sqrt[4]{\varepsilon^2 + (60\lambda\sigma)^2}} e^{i\left[\omega\left(t - \frac{h}{v}\right) + \alpha\right]}. \tag{3.14}$$

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For the sea, which approaches conductors in terms of its properties, the absorption coefficient, δ, is found from equation (2.5).

After certain transforms we get:

$$E_{2x} = \frac{E_{1z}}{\sqrt{60\lambda\sigma}} e^{-2\pi \sqrt{\frac{30\sigma}{\lambda}} h}; \tag{3.15}$$

$$E_{2x} = \frac{E_{1z}}{\sqrt{60\lambda\sigma}} e^{-\delta h}. \tag{3.16}$$

Accordingly, the vertical component beneath the surface of the water at depth h is determined by the equation:

$$E_{2z} = \frac{E_{1z}}{\sqrt{60\lambda\sigma}} e^{-\delta h}. \tag{3.17}$$

Calculations made with equation (2.5) and presented in table 3.1 show that δ increases with an increase in the conductivity of the water. For a characterization of the attenuation of radio waves in different types of soil and in sea water, a determination was made of the limiting distances starting with which practically total attenuation of a wave takes place in these media (the field strength of an electromagnetic wave is reduced a millionfold). These limiting distances are given in table 3.2 [38].

It is obvious from tables 3.1 and 3.2 that at a specific depth attenuation of the signal is slighter, the lower the frequency, and that for the accomplishment of radio communications with objects submerged in water only VLF and ULF waves are applicable.

With an increase in frequency, losses of the wave's energy are strongly increased, since dielectric losses are added to conduction losses. The total reduction in field strength is expressed by means of factor K_E, which indicates by how great a factor the field strength of the signal above the point of submersion must be increased in order to compensate energy losses as h increases (fig 3.2):

$$K_E = e^{-\delta h} \frac{E_{1z}}{E_{2z}} = e^{-\delta h} \sqrt{60\lambda\sigma}. \tag{3.18}$$

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Table 3.1.

1) Диапазон	λ, м	f, Гц 2)	σ, См/м					
			1	2	3	4	5	6
3) СДВ	300	10^6	1,99	2,81	3,44	3,98	4,47	4,85
	30 000	10 000	0,198	0,284	0,347	0,402	0,445	0,48
	60 000	5 000	0,141	0,202	0,243	0,281	0,314	0,344
	100 000	3 000	0,109	0,154	0,188	0,218	0,244	0,267
4) СНЧ	$1 \cdot 10^6$	300	0,034	0,049	0,059	0,069	0,077	0,084
	$4 \cdot 10^6$	75	0,017	0,024	0,030	0,034	0,039	0,042
	$5 \cdot 10^6$	60	0,015	0,020	0,025	0,031	0,034	0,038
	$1 \cdot 10^7$	30	0,011	0,015	0,019	0,218	0,024	0,027

Key:
1. Band
2. f, Hz
3. VLF
4. ULF

Table 3.2.

λ, м	1) Предельные расстояния распространения, м		
	2) сухая почва	3) влажная почва	4) морская вода
	$\varepsilon = 4$, $\sigma = 10^{-3}$ См/м	$\varepsilon = 10$, $\sigma = 10^{-2}$ См/м	$\varepsilon = 80$, $\sigma = 4$ См/м
3	147	23,2	0,37
300	210	70	3,5
30 000	1800	700	35

Key:
1. Limiting distances for propagation, m
2. Dry soil
3. Wet soil
4. Sea water

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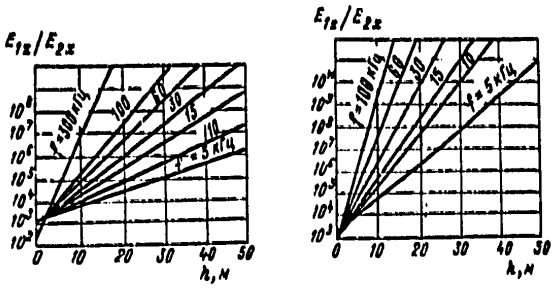

Figure 3.2. Graph for Calculating Factor K_E

Key:
1. f = 5 kHz

In recent years, abroad interest has grown in studying the propagation of ULF waves (from 30 to 100 Hz), which is related primarily to finding a solution to the problem of communications with submarines at great depths in any area of the global ocean. For this purpose, in the USA, starting in 1958, scientific research studies have been made on ULF communications, and the Sanguine ELF system has been created [82, 88, 90, 95].

The following are typical of the ULF band (most probable operating frequencies for communications, 45 to 75 Hz):

Low influence of the atmosphere on the attenuation of electromagnetic energy (depending on the time of day, the absorption coefficient at f = 75 Hz is $0.7 \cdot 10^{-3}$ to $1.5 \cdot 10^{-3}$ dB/km [95], and for f = 45 Hz, over the Pacific Ocean, in propagation from east to west, $0.9 \cdot 10^{-3}$ dB/km [90], which ensures reliable and stable radio communications from one radio center).

Low absorption in sea water of radio waves of this band (at f = 75 Hz--0.3 dB/m, and at f = 45 Hz--0.23 dB/m [90, 95], which enables the reception of signals at great depths).

Insensitivity to interference from the effect of nuclear explosions, which do not cause any significant reduction in the field strength of the useful signal.

The value of E_{1z} (μV/m) can be calculated from the semi-empirical equation in [86, 90]:

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$$E_{1z} \approx \frac{1}{2}\sqrt{\frac{2\pi\mu_0}{c}} fIL \frac{D^{0.5}}{H_i\sqrt{\sigma_3}} e^{-\delta_a r} \times \times \sqrt{\frac{1}{a\sin\frac{r}{a}}\cos\theta}, \tag{3.19}$$

where μ_0 is the magnetic permeability of a vacuum, in H/m; c is the speed of light, in m/s; H_i is the altitude of the ionosphere, in m; σ_e is the effective conductivity of the ground, in cm/m; f is the vibration frequency, in Hz; I is the current in the antenna, in A; L is the effective length of the antenna, in m; D is the gain of the antenna; δ_a is the atmospheric attenuation factor, in dB/km; r is the distance between the transmitter and receiver, in m; a is the radius of Earth, in m; θ is the angle of rotation of the directivity diagram of the transmitter's antenna in relation to the receiving antenna.

The electric field strength (μV/m) in sea water at depth h (m) is calculated by the equation:

$$E_{2z} = E_{1z}\sqrt{\frac{2\pi f\varepsilon_0}{\sigma}} e^{-\delta_v h}, \tag{3.20}$$

where ε_0 is the dielectric constant of free space; δ_v is the attenuation factor in sea water, in dB/m; σ is the conductivity of sea water in cm/m.

Influencing the range and depth of underwater radio reception, in addition to these factors, are the power of the electromagnetic field radiated by the transmitter, the noise level at the point of reception, and the sensitivity of the submarine's radio receiving equipment.

For the purpose of enabling communications with submarines, in the USA, in the VLF band radio transmitters with a power of 1000 to 2000 kW are used chiefly, with complex antenna systems. In the ULF band, the power of an experimental transmitter is 100 to 120 W, and the total power of a ULF transmitter, 10 MW.

The chief noise which must be taken into account in the reception of VLF and ULF signals in the submerged position is divided into three kinds: atmospheric; that induced by the electromagnetic field of the submarine; and the antenna's intrinsic noise. The level of atmospheric noise is 50 to 60 dB per 1 μV/m in the 1 Hz band [90], and peaks (resulting from lightning discharges) can be clipped by means of clippers, which gives a reduction in noise level to 20 dB [95]. As the useful signal and atmospheric noise travel through the water they are attenuated to a different extent, and, consequently, the

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signal-to-noise ratio does not depend on the depth of underwater reception [95]. The electromagnetic field is induced by alternating currents which arise between the unlike metallic parts of the hull of the submarine in sea water (the latter in this case is the electrolyte). The most effective measure for reducing the influence of the electromagnetic field on reception of the useful signal is to remove the antenna by means of a tug beyond the range of the electromagnetic field. The intrinsic noise of the antenna--"velocity noise" [21, 39]--which arises in towing as the result of vibration of the antenna in the magnetic field of Earth does not depend on depth. Beginning with a certain depth, the antenna's intrinsic noise begins to predominate over atmospheric noise.

Table 3.3

1) f, кГц	λ, м	E_n 2) мкВ/м	r, км	h, м: 3) при σ = 1 См/м	h, м: 4) при σ = 6 См/м
10	30 000	200	7800	14	7
15	20 000	130	7200	12	5,5
20	15 000	100	6800	11	5
30	10 000	65	6500	9	4
60	5 000	40	6000	5	3

Key:
1. f, kHz
2. E_n, μV/m
3. With σ = 1 cm/m
4. With σ = 6 cm/m

The communications range and depths of underwater reception possible thereby when using a VLF radio transmitter with a power of P_0 = 1000 kW and a stationary ideal antenna, as well as a special radio receiver with a ferrite loop antenna without taking into account atmospheric noise are given in table 3.3 [37]. As is obvious from this table, certain radio reception (K_1 = = 2) is possible at distances to 8000 km.

For the purpose of determining h and r with other values, it is necessary to interpolate. This can be done with the graphs in fig 3.3. The gain, K_h, for different r and λ with a reduction in σ from 6 to 1 cm/m (K_h) is determined from the graph in fig 3.3a. With reduction in conductivity i to a value of σ, accordingly the value of K_h is also reduced to $K_{h\sigma}$, which is determined from the graph in fig 3.3b. Thus, the value of h_σ can be calculated by the equation:

$$h_\sigma = h_{\sigma=6} K_{h\sigma}, \tag{3.21}$$

where $h_{\sigma=6}$ is the depth of immersion of the antenna in sea water with σ = 6 cm/m.

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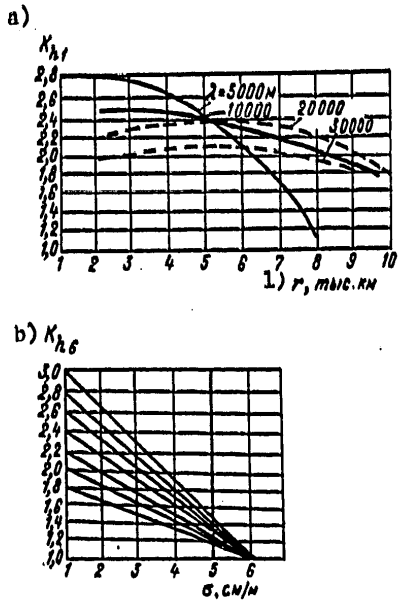

Figure 3.3. Gain in Depth of Underwater Reception with Reduction in Conductivity: a--K_{h1} ; b--$K_{h\sigma}$

Key:
1. r, thousand km

The range of radio communications is calculated similarly to r in the VLF band (cf. sec 2.2), taking into account the specified depth of underwater reception, h , and the conductivity of the water, σ .

Calculations can be simplified considerably if precalculated graphs are available for specific radio communications facilities and antenna equipment. For example, the graphs given in fig 3.3 make it possible to determine quickly many radio communications parameters (r, h , f_{opt} or frequency bands).

For the purpose of calculating h in the ULF band, in addition to the parameters enumerated for calculations of underwater radio reception in the VLF band, it is necessary to know certain additional data, such as, for example, the time of day (day or night) for carrying out communications, the altitude of the ionosphere, values of atmospheric attenuation factors, and of factors for the attenuation of radio waves in sea water, etc.

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The procedure includes calculations of strength, E_{1z}, at distance r with equation (3.19), and of the electric field strength in sea water, E_{2x}, at depth h with equation (3.20), and the verification of the conditions for the feasibility of accomplishing a specified quality of radio communications, K_1, in keeping with equation (2.11).

For the purpose of providing for labor intensive calculations of r and h in the ULF range when employing a radio transmitter similar to the Sanguine (P_0 = 10 MW, $\eta = 10^{-4}$), the authors developed a procedure whereby calculations are made with a computer. The calculation data are divided into parameters with constant and variable values. The following parameters with constant values are used [21, 73, 82, 86, 90, 95]:

$$\mu_0 = 4\pi \cdot 10^{-7}\ \text{Н/м};\quad c = 3 \cdot 10^8\ \text{м/с};$$
$$IL = 1{,}1 \cdot 10^9\ \text{А·м};\quad D = 1{,}5;$$
$$\sigma_в = 1{,}2 \cdot 10^{-4}\ \text{См/м};\quad a = 6370\ \text{км};$$
$$\varepsilon_0 = \frac{1}{36\pi} \cdot 10^{-9}\ ,$$

as well as the following variable parameters:

$$f = 45;\ f = 75\ \text{Гц};$$
$$H_l\ (\text{day}) = 5{,}5 \cdot 10^4\ \text{м};\quad H_l\ (\text{night}) = 8 \cdot 10^4\ \text{м};$$
$$\delta_a\ (\text{day}) = 0{,}176 \cdot 10^{-6}\ \text{dB/m};$$
$$\delta_a\ (\text{night}) = 0{,}92 \cdot 10^{-6}\ \text{dB/m}.$$

The results of calculations of E_{2x} for f = 75 Hz are given in table 3.4 (as a function of h at $r = 0.2 \cdot 10^3$ km, at night, with σ = 3, 4, 5 and 6 cm/m) and in the graph in fig 3.4.

Table 3.4

h, м	1) E_{2x}, мкВ/м			
	σ = 3 См/м	σ = 4 См/м	σ = 5 См/м	σ = 6 См/м
50	0,0377	0,033	0,03	0,027
100	0,0069	0,006	0,0053	0,005
150	0,0013	0,0011	0,00097	0,0009
200	0,00023	0,0002	0,00018	0,00015

[Key on following page]

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Key:
1. E_{2x} , μV/m

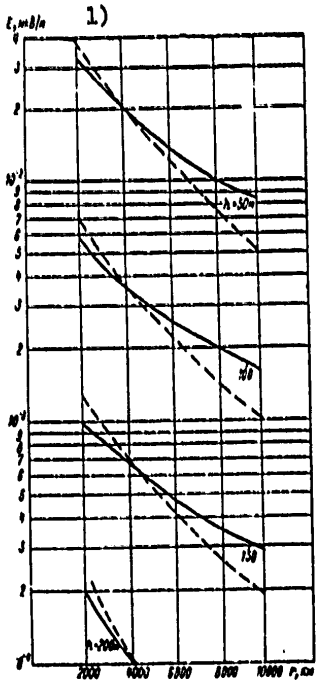

Figure 3.4. Dependence of Electric Field Strength in Sea Water on r with $\sigma = 4$ cm/m , $f = 75$ Hz , $h = 50$, 100, 150 and 200 m ; _____ in Daytime and ----- at Night

Key:
1. E , μV/m

An analysis of calculations has shown that with an increase in the conductivity of water the depth of reception is reduced, however this influence is considerably slighter than in the VLF band. At communications distances greater than $4 \cdot 10^3$ km, the field strength is greater in daytime than at night, and at smaller distances, vice-versa. Certain reception of messages (with a signal-to-noise ratio equal to 3 dB) can be ensured at depths up to 150 m and with a communications range up to 10,000 km.

The operating frequency to a considerable degree also determines the communications range. Since with a lowering of frequency the attenuation factor is

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reduced, then accordingly for the purpose of extending the communications range it is necessary to change to lower frequencies. But the field strength of the signal is proportionate to the frequency. In addition, it is necessary to take into account the change in the effective level of atmospheric noise with frequency. The presence of such contradictory factors requires the selection of the optimal frequency for a specified communications range, whereby maintenance of the constancy of the signal-to-noise ratio will be ensured. Studies have shown that for a communications range of $5 \cdot 10^3$, 10^4 and $15 \cdot 10^4$ km, the optimal operating frequencies are respectively 150, 75 and 50 Hz [90].

3.2. Features of the Propagation of Sound in Water and Calculation of Hydroacoustic Communications Lines

The transmission of information in a marine environment through a hydroacoustic communications channel is accomplished by means of acoustic vibrations. A marine environment absorbs acoustic energy least of all kinds of energy. A hydroacoustic channel is the least studied communications channel, but it is widely employed for communications with submarines and deepwater instruments and divers, as well as for telemetry, identification and remote control in the water.

The propagation of acoustic waves and the reception of signals is influenced by distortion of the path of acoustic beams caused by a change in the speed of sound with depth, diminishment of the intensity of acoustic waves with an increase in distance from the sound source, and by hydroacoustic noise and interference, which hamper the reception of useful signals.

The propagation of hydroacoustic signals depends primarily on the state of the sound velocity field, whose parameters are determined by hydrophysical parameters of the sea--by the values of the temperature, t , salinity, S , and pressure, p . The dependence of the speed of sound in the sea (m/s) on t , S and p has been established experimentally, and it can be estimated by Wood's approximation equation:

$$c = 1450 + 4{,}206t - 0{,}0366t^2 + 1{,}137(S - 35) + 0{,}0175h. \quad (3.22)$$

(3.22)

From equation (3.22) it is obvious that with an increase in t , S and p the speed of sound in the ocean increases. The temperature exerts the greatest influence on the speed of sound. Although the influence of these factors on a change in the absolute value of c is not too great (within the range of 1440 to 1540 m/s), nevertheless they play an important role in the propagation of sound because of the refraction of acoustic beams. For the purpose of determining the speed of sound it is convenient to use the nomograms and tables presented in [71, 85]. Frequently employed are not the absolute values of t , S and p , but their increments with depth, i.e., their gradients, G .

Let us consider some typical cases of the distribution of the speed of sound at different depths, each of which has its refraction pattern (fig 3.5).

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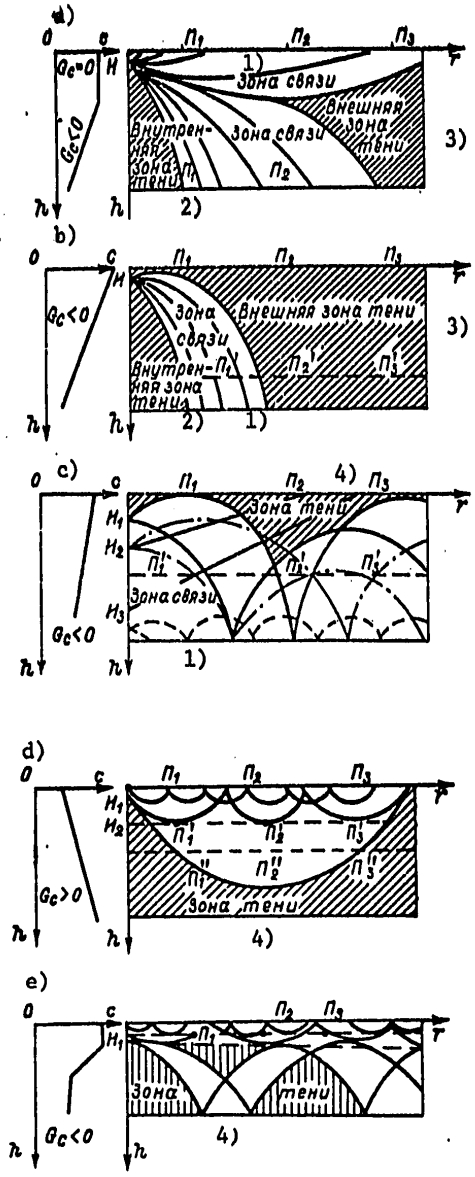

Figure 3.5. [Continued on following page]

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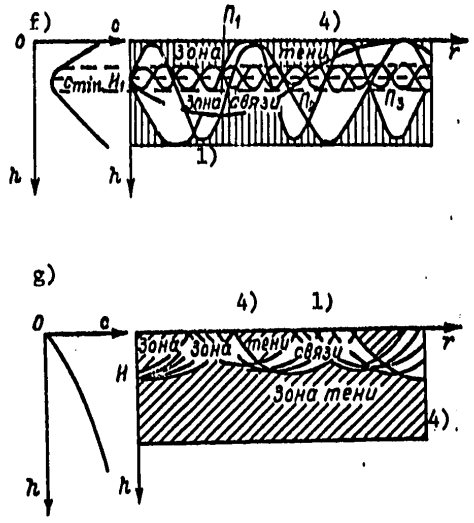

Figure 3.5. Communications Zones with Different Kinds of Refraction: a--with the presence of an isothermal surface layer; b--with negative refraction; c--with negative refraction in a shallow sea; d--with positive refraction; e--with the presence of a layer of discontinuity; f--with the presence of PZK [underwater sound channel]; g--with the presence of ice

Key:

1. Communications zone
2. Internal shadow zone
3. External shadow zone
4. Shadow zone

The first case--isothermy in the surface layer, which can reach dozens of meters, whereby below this layer the temperature of the water drops with depth--is negative refraction (fig 3.5a). This phenomenon is caused by the constancy of t in the surface layer because of the mixing of masses of water by the wind or by waves. Acoustic beams leaving the sound source at narrow angles to the horizon experience slight distortion in the direction of the suface, and at wide angles in the direction of layers with lower speed, in the direction of the floor. Thus, the communications zone is split and two acoustic shadow zones (an internal and external) are formed.

The second case (fig 3.5b) is when the speed of sound is reduced with depth, which is typical of the spring-summer period. In the daytime the surface layer of the water is heated by the sun more intensely than lower layers, as

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a result of which acoustic waves are heavily distorted in the direction of the floor (negative refraction) and conditions for communications are drastically worsened. The existence of communications depends on distance r to the source, I , and its position in relationship to the receivers, P , at the depth. A variety of this case is the condition for communications with negative refraction in a shallow sea (fig 3.5c). As the result of multiple reflection of acoustic waves from the floor, the communications zone is enlarged.

The third case--positive refraction (fig 3.5d)--is observed in the spring-summer period of the year. During this period the surface of the sea gives up more heat than it gains, and a positive temperature gradient is formed, which also causes a positive gradient in the speed of sound. As a result, acoustic beams are deflected in the direction of cold layers, i.e., in the direction of the surface of the sea, and are concentrated near it. These beams, after refraction, can be reflected from the surface of the sea more than once, and practically without loss of acoustic energy. Communications conditions are favorable.

It is obvious from fig 3.5b, c, d that with the same distance between correspondents their receivers can happen upon both a shadow zone and a communications zone. If steady communications is required with $G_c > 0$, then the correspondents should be situated at the surface, and with $G_c < 0$, at the floor.

The fourth case is the presence of a layer of discontinuity (fig 3.5e), up to 50 m thick, with a sudden change in the speed of sound ($G_c < 0$). Acoustic beams are distorted above the layer of discontinuity, as with the presence of a positive gradient in the speed of sound. The layer of discontinuity causes intense attenuation of the strength of acoustic waves passing through it (by a factor of two to three), and conditions for hydroacoustic communications are considerably worsened. In addition, the negative refraction which occurs in this case generally restricts the range of hydroacoustic communications to not too great distances.

The fifth case is communications with the presence of an underwater sound channel (PZK), which forms when down to a certain depth the speed of sound first drops, and then, having reached a minimum, begins suddenly to grow with an increase in depth, as a result of the joint effect of a change in the temperature of the water, salinity, and hydroacoustic pressure, and as a result of the influence of warm streams near the floor and in deep water (fig 3.5f).

A PZK represents a waveguide in which sound is propagated at the same rate. Sound channels are divided into hydrostatic, when the speed of sound increases with depth under the influence of increasing pressure, and thermal, when c increases under the effect of warm waters. Thus, alternating refraction is observed, and since beams leave the source with different angles of emission, then each beam will describe its own trajectory and the common movement of beams will be observed along the axis of the PZK.

The axis of the channel is considered the depth at which the speed of sound is minimal (c_{min}). When the source is located on the axis of the PZK the sound

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is focused within the limits of the layer, the wave front is not broadened with distance, attenuation of the signal is minimal, and extra-long-range hydroacoustic communications is observed within the limits of the PZK. In American publications a description is given of a case in which the explosion of a 22.5-kg bomb was heard on the axis of a PZK at a distance of 19,200 km through the Indian and Atlantic oceans.

A PZK can be thermal and surface, originating at a depth of 20 to 80 m in the spring and disappearing in the fall, and deepwater and hydrostatic, existing throughout the entire year. Deepwater PZK's are found in oceans at various depths: at equatorial latitudes of the Atlantic, at a depth of $h = 1000$ to 1200 m, at higher latitudes at $h = 300$ to 400 m, and in the Pacific Ocean at a depth of 500 to 700 m. In equatorial regions the thickness of a PZK is 4000 to 5000 m, and in subpolar regions, this depends on the time of year: 1500 to 3000 m in the summer, and reducing to zero in the winter.

If the speed of sound at the floor is greater than the speed of sound at the surface of the sea, then periodic focusing of acoustic energy takes place in regions of secondary emergence of beams at the surface of the ocean (secondary zones of exposure) at a distance on the order of 50 km from the source.

It is of interest to consider the features of the propagation of sound under ice. The temperature of the water in the Arctic increases with depth, in connection with which the speed of sound also increases. The acoustic refraction pattern is illustrated in fig 3.5g, from which it is obvious that acoustic beams, undergoing multiple reflection from the ice with a 6-km reflection cycle, are concentrated in a relatively thin layer of water--a surface sound channel along the water-ice interface.

The intensity in the diminution of acoustic waves in water with distance occurs for three reasons: because of the absorption of sound in the water, broadening of the wave front and scattering.

The absorption of sound in water (dB/km) depends on the frequency (kHz), and without taking into account the influence of t, S and p, is expressed by the equation

$$\beta = 0{,}036 f^{2}. \qquad (3.23)$$

The values of β, computed by this equation, are given in fig 3.6. In the frequency range from 10 kHz and above, experimental equation (3.23) agrees with the theoretical studies in [92]. However, in the region of lower frequencies the discrepancies are considerable [71]. Under real conditions the absorption of sound depends in addition on the specific values of t, p and S and can be calculated by the equations given in the literature [50, 71].

The diminution in the intensity of the signal, J_s, with distance, r, in km, is associated with broadening of the wave front. The strength of the signal

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(W/cm^2) at the reception point, for spherical waves (the most typical case in hydroacoustic communications), is determined by the equation

$$J_r = \frac{I_0}{4\pi r^2} \cdot 10^{-0.1\beta r}, \tag{3.24}$$

where I_0 is the intensity of acoustic vibrations at their point of origin, and $4\pi r^2$ is the area of a sphere with radius r in cm^2.

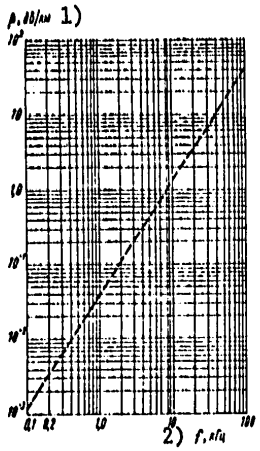

Figure 3.6. Dependence of Attenuation Factor on Frequency

Key:
1. β, dB/km
2. f, kHz

The strength of signals is reduced because of the scattering of sound in the water.

In the operation of hydroacoustic communications stations, reception of the useful signal always occurs against the background of hydroacoustic noise and interference, which include noise in the sea, etc. With regard to intensity, ship interference (noise of the propeller) is the most powerful. At high ship speeds powerful cavitation noise is created over a wide frequency range.

The strength of noise interference which is perceived by a receiver with a passband of Δf (Hz) is determined by the equation [71]:

$$J = \frac{a_n \Delta f}{f^2 \gamma} \left(\frac{V}{V_0}\right)^6, \tag{3.25}$$

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where a_p is the intensity of interference measured at $f = 1$ kHz in the $\Delta f = 1$ Hz band and determined at a ship speed of V_0 ; V is the rate of travel of the ship making the noise, in knots; f^0 is the operating frequency of the communications station in kHz; and γ is the axial concentration factor, which for a plane transmitter (receiver) equals

$$\gamma = \frac{4\pi S}{\lambda^2} = \frac{4\pi S f^2}{c^2}, \tag{3.26}$$

where S is the area of the working surface of the transmitter, in m^2.

An analysis of equation (3.25) demonstrates that the strength of the noise to which the receiver reacts is proportional to the frequency passband and inversely proportional to the square of the operating frequency. Consequently, in hydroacoustic communications stations it is advisable to narrow the frequency band. However, the constriction of Δf is limited by the reception of short pulses and the Doppler effect. For the purpose of diminishing the influence of interference in hydroacoustic communications equipment, single-band communications systems are widely employed. In addition, the noise is attenuated by a factor of γ in the case of employment of a directional receiver as compared with a non-directional, and its strength increases in proportion to the speed, V , of the noise-making ship to the sixth power.

Let us consider the key parameters of hydroacoustic communications lines.

The effective range of a hydroacoustic communications station depends on various factors: the technical parameters of the equipment, conditions for the propagation of sound in the ocean, the noise level at the point of reception, etc. The attempt to unite all magnitudes influencing the effective range in one equation has not yielded positive results. Therefore, in hydroacoustics the range of stations is estimated by estimating the geometric range limited by refraction and the energy range, limited by the energy capabilities of the equipment. Then these ranges are compared and the minimum is assumed to be the actual.

By geometric range is meant the distance from the sound source to the shadow boundary, i.e., the communications zone, which depends on the magnitude of the sound speed gradient, the nature of the vertical distribution of the speed of sound, the exit angle of the beam from the source, and the depth of submersion of correspondents. For the simplest cases the geometric effective range, r_g (m), is calculated with the following equations:

with negative refraction and the transmitter located at the surface and the receiver at depth h_2 ,

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$$r_r = \sqrt{2h_1 \frac{c_0}{G_c}};$$

(3.27)

with negative refraction and the transmitter at depth h_1,

$$r_r = \sqrt{2 \frac{c_0}{G_c}} (\sqrt{h_1} + \sqrt{h_2});$$

(3.28)

and with positive refraction,

$$r_r = \sqrt{2 \frac{c_{OH}}{G_c}} (\sqrt{H - h_1} + \sqrt{H - h_2}),$$

(3.29)

where H is the depth at which reflection of the beam from the intermediate layer takes place at the angle of internal reflection; c_0 is the speed of sound at the level of the radiating element, in m/s; c_{OH} is the speed of sound at depth H, in meters.

The value of G_c can be determined by means of special instruments or from the temperature gradient:

$$G_c(t) = (4{,}21 - 0{,}073t) G_t,$$

(3.30)

where t is the temperature between the surface of the sea and the depth of submersion.

In more complex cases of refraction this calculation is performed by means of an electronic beam plotter, and in its absence with a special plotting board.

The energy range is determined by the minimal strength of the signal, $J_{s\ min}$, with which it can be registered with predetermined probability against a background of noise, J_p:

$$J_{c\ min} = \delta^2 J_n,$$

(3.31)

where δ is the threshold coefficient which can be determined from the equation:

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$$\frac{\delta^2}{\sqrt{1+2\delta^2}} = \frac{K_\delta}{\sqrt{\Delta f t}}, \tag{3.32}$$

where K is a factor characterizing the necessary ratio of J_s/J_p ensuring reception of the signal with predetermined probability (characterizes the reliability of the reception of messages); t is the time for averaging of the signal (in s), i.e., the time during which the received signal is averaged by the receiver-amplifier (usually an RC filter).

The ratio of K_δ/δ characterizes the quality of the receiving-and-amplifying channel and its noise rejection.

The threshold coefficient for the case of hydroacoustic communications is determined by the equation:

$$\delta = \frac{\sqrt{2K_\delta}}{\sqrt{\Delta f t}}. \tag{3.33}$$

Equation (3.31) is transcendental and is solved by the graphic analysis method. First of all it is necessary to establish the relationship of J_s (W/cm^2) as a function of r (km). For hydroacoustic communications equipment, J_s has the form:

$$J_c = \frac{P_a \gamma}{4\pi r^2} \cdot 10^{-0.1\beta r}, \tag{3.34}$$

where P_a is the radiated power in watts.

Knowing the values of P_a, γ and β, and assigning a number of values for distance r, it is possible to determine the corresponding value of J_s (fig 3.7). By plotting the $J_s = \phi(r)$ curve and making a straight line corresponding to the value of J_s level J_p taking into account the value of at the point of reception, we get the point of intersection of lines, and projecting this onto the X axis, we find the value of the energy range of the hydroacoustic communications equipment.

The range of hydroacoustic communications, r (km), between two vessels (submarines) can be calculated by the equation:

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$$r = 32{,}6\frac{V_0}{V}\sqrt[6]{\frac{AtP_a S^2}{a_{11}K_\delta^2}}, \tag{3.35}$$

where A is the anomaly factor, characterizing the ratio of the strength, J_r, of the acoustic field in the refracting medium to the strength of sound, J_0^r, in a homogeneous boundless medium at distance r from the source, i.e.,

$$A = \frac{J_p}{J_0}. \tag{3.36}$$

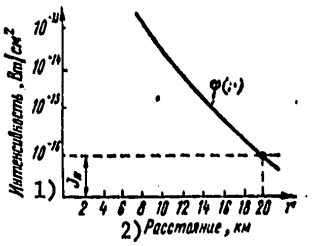

Figure 3.7. Graph for Determining the Energy Range for Hydroacoustic Communications

Key:
1. Strength, W/cm^2
2. Distance, km

Thus, for the purpose of increasing the range of hydroacoustic communications, it is necessary to increase P_a, reduce the speed of the vessel and reduce the noise interference. Increasing P_a is limited by the cavitation phenomenon which originates at the surface of the radiating element and near it. The tentative value of the amount of unit power with which cavitation originates equals 0.3 W/cm^2. The greater the depth of submersion of the radiating element, the operating frequency and the overall dimensions of the antenna, and the shorter the duration of the sending of the signal, the greater the maximum permissible unit power to be supplied which is limited by cavitation.

Calculation of the energy range is highly labor intensive, and for speeding up this process special nomograms are employed.

The operating frequency, f, of hydroacoustic communications equipment to a considerable degree also determines the communications range, since a parameter such as γ, for example, is responsible for an increase in range with an increase in f, and β for its reduction. This opposing influence

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of different factors results in the existence of an optimal frequency. The optimal frequency minimizes the radiated power with an assigned effective range and other constant communications parameters and is determined from equation (3.31) by the formula:

$$f_{опт} = \frac{62}{r^{3/4}}, \tag{3.37}$$

But equation (3.37) does not satisfy requirements from the viewpoint of maximizing the information transmission rate and the carrying capacity of the communications channel.

Assuming that the signal is propagated in a homogeneous medium, the diminution of its strength takes place according to a spherical law, that attenuation is determined from equation (3.23), and that the noise level of the sea diminishes by 5 dB per octave, the general equation for the optimal frequency corresponding to predetermined P_a and r will equal [50]:

$$f_{опт} = \left\{ \frac{\left(1 + \frac{N}{P_a}\right) \frac{6{,}72}{\log_2\left(1 + \frac{P_a}{N}\right) + 1}}{0{,}026 r} \right\}^{3/4}, \tag{3.38}$$

where N is the power of interference in the form of white Gaussian noise in watts.

In the propagation of signals, certain specific features occur which influence the rate of information transmission, its certainty and the range of hydroacoustic communications. Included primarily among these are distortions of signals (amplitude, phase and frequency), time distortions (pulling of signals), etc. The main reasons for these distortions are the multi-beam nature of propagation and Doppler broadening of the frequency range.

Multibeam propagation results in amplitude distortions and in different kinds of signal fading, which have much in common with the fading phenomena of radio signals. In [71] are presented equations and nomograms for calculating the number of incoming beams and the difference in time delays of signals propagated through different beams, which can equal, e.g., from 4 to 2000 ms [90]. For the purpose of reducing this influence, information transmission rates are increased and complex methods of modulation are employed (frequency keying and frequency coding) and directional reception with an acoustic antenna, signal power is increased, space diversity is employed, etc.

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A Doppler frequency shift occurs during movement of the radiating element and receiver, and the value of the frequency received differs from the frequency of the radiating element, f_0. For the reception of signals it is necessary that the receiver have a maximum absolute passband value equal to $|\Delta f| = 2f_0(V_{otn\ [relative]}/c)$.

The conditions for the transmission of information through a hydroacoustic communications channel and through radio channels (VLF and ULF) have substantial differences, which can be reduced to the following:

The considerably slower rate of propagation of acoustic waves as compared with electromagnetic (in radio communications within the limits of Earth there is practically no delay in the correspondent's response, but in hydroacoustic communications at a distance of 185 km a response will be received only every 4.1 min).

The considerably greater dependence of the trajectories of the propagation of acoustic waves on the physical parameters of the characteristics of the propagation medium (in radio communications this dependence is practically absent).

The frequency pulling of pulses as a function of communications distances (in a radio channel, not greater than 0.1 to 10 ms, and in a hydroacoustic channel at a distance of up to 50 km--10 to 2000 ms, and up to 500 km, greater than 1200 ms).

The considerably higher noise level at the reception point and the dependence of reception quality on the state of the medium, intrinsic hydroacoustic noise, and ship noise.

The considerably lower attenuation factor for sound in the sea as compared with the attentuation of electromagnetic waves in water (at $f = 75$ Hz the attenuation of sound equals 0.027 dB/km, and the attenuation of electromagnetic waves in water, 0.3 dB/km). These differences must be known and taken into account in designing and using communications equipment for submarines and underwater instruments.

Chapter 4. General Regulations Regarding the Organization of Systems and the Employment of Communications with Craft and Ships

"Organization" and "system" are closely related concepts. There is no organization without a system and there is no system which does have organization. The word "organization" has many meanings, including the process of transforming a disordered phenomenon into an ordered one, and of bringing elements and components into a whole, a system, as well as the result of this process--the design and structure of the whole, of the system.

With regard to a communications system, organization must be understood also in two aspects:

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1. The process of incorporating in a system communications facilities and personnel making possible the exchange of information with control, which is accomplished to the total extent in creating the system or in part while improving it, for the purpose of achieving the necessary efficiency under anticipated conditions of circumstances with the lowest expenditure of facilities and personnel, and, for radio communications, of radio frequencies as well. It includes a number of measures which it is necessary to carry out in advance.

2. The design, the structure of the communications system.

4.1. Structure of a Communications System

By the structure, the design, of a system in the broad sense is meant the overall qualitatively determined and relatively stable sequence of space-time relationships and of relationships between its components (elements, subsystems), ordered as a function of the hierarchical level of these components, of functional interrelationships, and of operating conditions and procedure, and governing the functioning of the system as a whole and the nature of its interaction with other systems and the environment. On this basis it follows that the structure of a communications system should contain the components of the system and their interrelationship, which determine or substantially influence the functioning of the communications system as a whole. A detailed analysis of the components of a system is defined in relation to the purposes of the discussion, and in their interrelationships are isolated those components without which functioning of the system and achievement of the goals of its functioning are impossible.

In general form the structure of a communications system can be represented as a system of communications centers connected by communications lines. An analysis of this structure makes it possible to distinguish two main methods of constructing systems.

The first method calls for the connection of each communications point with every other one (fig 4.1) and is called the junction point method (or the "junction point system" method). The number of communications lines, L , required with this method for n points is $L = n(n-1)/2$, and with a large number of communications points, $L = n^2/2$. Consequently, the number of communications lines increases in proportion to the square of the number of points. Therefore, with a great number of communications points this method cannot be considered economical. In addition, considerable supplies of equipment are required, as well as high-power radio transmitters and ideal radio receiving equipment for communications with all points.

However this method also has considerable advantages: a) The absence of intermediate connections, and consequently of retransmission; b) maximum system switchability and flexibility; and c) high system stability, since when one line goes out of order it does not affect the operation of others and at the same time it is possible to compensate the failure of one line by using bypass lines through other communications points. A technical and

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economic analysis [25] has shown that the economic efficiency of a communications system increases with an increase in the number of messages passing through communications lines.

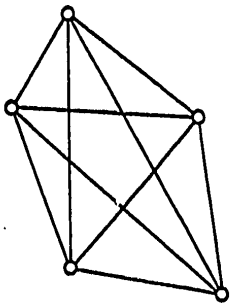

Figure 4.1. Junction Point Method of Designing a Communications System

Thus, it is advisable to use the junction point method for communications systems for major units (points), when high reliability and speed of communications are required, as well as system stability and flexibility, as well as with large load volumes. It can be used for communications between the ports of a single sea and for communications between vessels when conducting trade as part of a flotilla and in sailing together.

The second method of designing a system calls for the connection with communications lines of one point, selected by virtue of its importance or its central location (and very frequently by virtue of both), with all other points. Furthermore, this point is the intermediate point for intercommunications between remaining points (fig 4.2). This method is called the radial method (or the "radial system" method). The number of necessary communications lines for n points in this method is reduced to $L = n - 1$, and the carrying capacity of such a system is lowered considerably, but its economic efficiency is higher and increases with an increase in the load volume of the central point in relation to the load of the remaining points.

With this method the system has low stability: With damage to the central point the entire system goes out of order. With unfavorable conditions for the travel of radio waves, communications with individual points are easily disrupted. The central point is loaded with a great number of communications lines. For the purpose of carrying out radio communications at sea, when it is necessary to guide the operation of trade, transport and other vessels in different areas of the global ocean, this requires high standby power for radio transmitters. The radial method makes it possible to guide efficiently units from a central communications point. As a rule, the radial method is employed for communications systems covering not too large areas, with low loads for peripheral communications points and not too high requirements for

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the reliability and speed of communications. For a marine communications system this method can be used, e.g., for piloting an icebreaker, for the operation of commercial expeditionary vessels, etc.

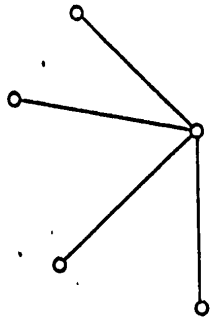

Figure 4.2. Radial Method of Designing a Communications System

The desire to utilize the advantages of these methods has led to the hybrid radial-junction method of designing a communications system (fig 4.3), which is the most advisable for marine communications systems. The base of this system is a group of large units having direct communications with one another and serving a specific important marine area. Locked into these centers are the smaller centers of sea ports, port points and vessels.

By virtue of the hierarchical nature of communications systems with different levels of control, the structures of communications systems of lower levels of control are components of the structure of communications systems of higher levels, thus forming distinctive stages of the control levels provided. In a system for communications with sea vessels, with the radial-junction method, the most efficient is a two-stage communications system [11, 63].

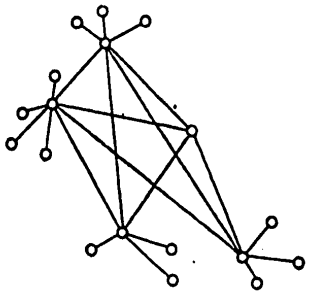

Figure 4.3. Radial-Junction Method of Designing a Communications System

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In the U.S. Navy communications system the radial-junction method of design is employed; therefore it is a multi-stage system. The structure of the U.S. Navy system is made up of six major (Washington, San Francisco, Honolulu, Guam, Balboa and Port Liote), 16 large, 25 small and 360 secondary communications units, interconnected by multi-channel trunk radio and cable communications lines. Furthermore, the small and secondary units are connected by the radial method with large units in relation to their own territorial zones, and large units are connected by the junction point method together and to the major communications units in the theater. The major units are interconnected, thus creating a global communications system. A ship establishes communications with the nearest communications center and through it can transmit a message or carry out two-way communications with a coastal control point (PU) or a ship in the area in question or located in another ocean theater.

For the purpose of a detailed analysis of the structures of modern communications systems it is necessary to take into account the entire variety of communications facilities, lines and types used for control, as well as the extensive and complex provisions for communications with vessels and ships over considerable distances (in practically almost all areas of the global ocean), and for communications with submerged submarines, as well as the high requirements for communications and communications systems.

Therefore, the complete structure of a communications system should include all components, detailed to the point of communications complexes and facilities, their location and hierarchical level, methods of organization and all important measures for ensuring communications under anticipated conditions.

The bottom level of the structure of a communications system should be the communications channel, which connects the sender with the receiver of information. The combination of channels for the transmission of information in the control system from the control agency (headquarters, command point) to controlled vessels and ships (from them to the control agency, between ships, etc.) makes up the communications route, which is the key element, the basic level of the structure of a communications system. The counter routes of two command levels in the exchange of information form a communications link. Each command level in the control system transmits and receives information along several K-routes, the combination of communications in which is customarily called command level communications. The combination of processes of the transmission, the reception and exchange of information along routes of interconnected command levels in the solution of problems makes up the communications of a group, squadron, flotilla and other similar subdivisions and combinations of vessels, ships, production organizations and formations. All the communications routes of M-command levels uniting them into a control system form the communications system.

Thus, radio, radio relay, wire and other communications facilities make up communications channels and routes, from which are created the following levels of the system's structure. Here the capabilities of a communications system depend to a considerable extent on by which method communications are organized, on what operating loads are provided, on how the operation of equipment is

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coordinated in a communications channel, in channels in each route, in communications routes and in the system as a whole, and, for naval communications systems, also on what measures have been provided for protecting communications from enemy reconnaissance and attack.

Generally the structure of a communications system includes the following: communications routes; radio networks and radio routes, and networks and routes for radio relay, wire and hydroacoustic communications; the operating loads of these networks and routes and the procedure for establishing communications in channels, for making service calls and transmitting messages; call stations, codes, passwords and other data on communications; and measures for protecting radio communications and radio relay communications from different kinds of noise. The structure of communications systems ensuring control in combat operations should also include measures for protecting from reconnaissance, enemy interference and the influence of nuclear explosions, measures for protecting communications structures from enemy fire and diversionary operations, and other measures.

Each communications system has a structure conforming to its purpose, anticipated information flow, the required quality of communications and conditions for carrying it out.

4.2. Measures in Organizing a Communications Channel and One-Way Communications

For the purpose of carrying out the transmission of messages in an electric communications channel, it is necessary in advance to select communications facilities (with the appropriate technical parameters) and to combine them into a communications channel, and to establish traffic rules (for service calls and for the transmission and reception of messages), general call data, frequencies and other data on communications, and SES [Station Operating Service] rules.

The selection of communications facilities and their connection for the purpose of ensuring high-quality operation of a channel should provide for the matching (compatibility) of facilities with respect to technical and information parameters, especially of terminal and transmitting and receiving equipment, with the selected communications line (radio, radio relay or wire). Here radio communications facilities are selected by taking into account the band of radio frequencies employed, the required range and communications conditions.

The establishment of traffic rules calls for a definite sequence ensuring speed and reliability (and in necessary instances, secrecy, too) in entering into communications, precise operation in the transmission and reception of messages, and also a procedure for conducting calls. Traffic rules have been developed on the basis of many years of experience in the utilization of communications channels; they are presented, e.g., in the form of rules for radio communications for the maritime fleet and of rules for radio communications for the fishing industry fleet [53, 54], reflecting the specifics of the Soviet marine radio service and taking into account international requirements.

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Thus, for the purpose of conducting service calls, in the Soviet maritime radio service about 200 different abbreviations are used, of which approximately 150 are at the same time international and have been approved by radio communications regulations for all countries [63]. For the purpose of conducting service calls, in the international marine radio service are used the service call codes Q and Z and call tables.

The establishment of communications data is necessary for entering into communications and for carrying it out. These include call letters, radio frequencies, and, for naval communications, radio passwords. Each communications station has been assigned call letters--its conventional designation. Radio stations have been assigned international call letters based on a table of the distribution of call signals by country, approved at international conferences [61, 63]. Here country membership is determined from the first or first two letters of the call sign. Call letters are assigned to radio stations by the appropriate authorities of countries, in the Soviet Union by the USSR Ministry of Communications State Inspectorate for Electrical Communications.

In naval communications call letters are assigned for the purpose of keeping secret the names of ships, communications units and stations, and official personnel.

A radio password is a conventional word or digit by means of which the membership of the radio station entering into communications is established.

A determination of Station Operating Service (SES) rules is required by personnel of communications units and stations in establishing the facts of entering into communications, carrying out service calls, formulating transmitted and received messages and keeping records of them, and in other work with messages (radiograms, telegrams, etc.). These rules are set forth in special instructions.

These measures must be carried out to the full extent in organizing each communications channel. However, taking into account the fact that new communications channels build up existing communications systems, existing data on communications and traffic and SES rules are used.

Along a single communications route often several communications channels are prepared; therefore, the volume of organization measures increases. For the purpose of transmission of information along a single route, it is necessary in advance to determine the number and structure of communications channels (for radio communications, to determine the frequency band), to develop technical and organizational measures for the purpose of achieving the required communications reliability under anticipated conditions of circumstances; to determine the procedure for the travel of messages in the communications system and to develop the necessary technical and organization measures for the purpose of achieving the required speed of communications; to determine the procedure for the transmission of messages and, when necessary, to develop measures for the purpose of achieving secrecy of communications;

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to determine data on communications and traffic and SES rules; and determine the number of communications personnel and communications standby equipment.

These measures are developed on the basis of calculations, the raw data for which are the parameters of the anticipated flow of information along the communications route in question, the required quality of communications, i.e., permissible communications indicators, indicators for equipment and the skills of communications specialists, the level of employment of communications subdivisions taking part in transmission and reception along the route in question, and conditions for carrying out communications (for radio communications, conditions for the travel of radio frequencies, the possibility of radio interference, etc.).

Let us discuss in greater detail measures for determining the priority for the travel of messages and for determining the number of communications personnel and standby equipment.

The priority of message transmission is determined in accordance with the system for the transmission of operating information in control and with the requirements for efficiency of communications. Taken into account here are the locations and level of employment of communications posts at the points of transmission, reception and retransmission, and the level of automation of communications. At the control point (PU) different variants of information travel are possible, but there are two major ones:

1. All the information entering from communications facilities arrives directly and only to the addressee. The travel of outgoing information from the sender directly to communications facilities is similar.

2. All incoming information from all communications facilities arrives at a single place (let us call this the information center, ITs), where it is processed and stored and, depending on the content of the message, is sent to the official personnel. Travel of outgoing information via the ITs to communications facilities is similar.

At the PU can be received also other variants of information traffic representing combinations of the major variants for different messages. With regard to this is established the priority for the transmission of messages in a communications system.

The number of communications personnel to be used on a specific route of a non-automated communications system is determined by taking into account the number of channels, S , and the number of operators per channel, n_{o_1} :

$$n_o = S n_{o_1}; \tag{4.1}$$

$$n_{o_1} = \frac{t_{\text{ВВХТ}} + t_{\text{ОТД}}}{t_{\text{ВВХТ}}}, \tag{4.2}$$

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where t_{vakht} [duty] is the length of time the operator performs his duties and t_{otd} [rest] is the duration of the rest period between periods of duty. This calculation can be made quickly from a nomogram (fig 4.4).

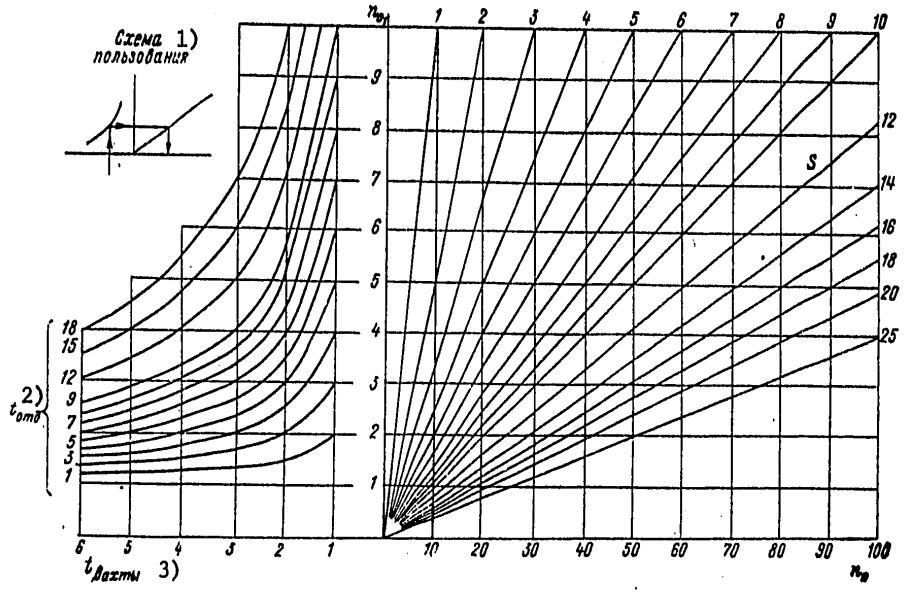

Figure 4.4. Nomogram for Calculating Number of Operators

Key:

1. Utilization diagram
2. t_{otd}
3. t_{vakht}

The number of engineering and technical personnel depends on the amount of equipment and the organization of the service. The level of skills of communications personnel, especially of operators, is determined by the required communications quality.

Determination of standby equipment is performed for the purpose of ensuring reliable communications along a given route. Standby facilities include communications equipment and operators. A distinction is made between technical standby facilities--the equipment for ensuring a required technical operating reliability of a communications channel--and service standby facilities--the number of communications channels, S_{rez}, and operators, $n_{o\ rez}$, for ensuring

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reliable communications with an increase in traffic intensity. It is obvious that the number of communications channels and operators is greater at maximum load (S_{max} and $n_{o_{max}}$) than with a mean load (S_{sr} and $n_{o_{sr}}$); therefore, service standby facilities equal:

$$S_{pes} = S_{max} - S_{cp}; \tag{4.3}$$

$$n_{o_{pes}} = n_{o_{max}} - n_{o_{cp}}. \tag{4.4}$$

With not too great a number of communications channels for a single route, a single standby force of communications facilities and operators is established for several routes.

4.3. Measures in Organizing Command Level Communications (Along K Routes) and a Communications System

For the purpose of accomplishing the transmission or reception of information along K command level communications routes, it is necessary beforehand to determine (precisely define) communications routes; to make calculations and develop coordinated measures for ensuring reliability along the first, second, third, etc., to the K-th route, and the stability of communications units, and to determine duplicating and bypass communications channels for important communications routes; to define precisely the arrangement for the transmission of messages along the K route, and to make calculations for the development of coordinated measures for ensuring speed of communications; where necessary, to make calculations and develop measures for ensuring the secrecy of communications on K routes; to determine efficient methods of organizing communications, the direction of traffic, and, for radio communications, methods of assigning and using frequencies; to coordinate and precisely define data on communications and traffic and SES rules for K routes; to allocate communications facilities and personnel for K routes; and to determine the standby force.

These measures are also developed on the basis of calculations. Let us consider in greater detail those which have not been considered previously.

Communications routes are determined on the basis of a diagram of the transmission of information and of information flows. Each information flow can comprise an independent communications route; however for purposes of shortening routes, for economizing on communications facilities, and for convenience of control, flows from a single command level are often united. Sometimes special information is isolated from the overall flow for the purpose of rapidity in delivering it to the addressee. In numbering routes, the first few numbers are assigned to the most important.

The determination of methods of organizing communications for a command level, which are different for different communications facilities, reduces to selecting an intelligent method under specific conditions for carrying out communications and for the existence of communications facilities.

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Radio communications can be organized with regard to radio network and radio route, as well as by entry into a radio network. Communications by radio relay and wire facilities on shore is carried out in relation to the route, axis and network.

For the purpose of determining the method of radio communications between a command level and other levels (craft, ships--information sources and users as a whole), it is necessary to know the system for the transmission of information, its anticipated flows, communications requirements and the capabilities of radio stations. A solution can be arrived at in several ways, one of which will be discussed below.

It is obligatory in organizing radio communications to determine the direction of traffic, radio frequencies and the procedure for their employment. The selection of the frequency band is determined by the required range, reliability and secrecy of communications, by the purpose of the radio network and by the presence of communications facilities. Here one always strives for the lowest number of employed radio frequencies; therefore, most often a common frequency is used for transmission and reception.

The number of radio frequencies used depends on reciprocal information flows and the carrying capacity of channels. Knowing these data, it is possible to estimate the feasibility of using a common radio frequency for two-way communications. For example, from point A to point B it is necessary to transmit a flow with parameters C_A, γ_{C_A}, q_A and γ_{q_A}, whereby transmission is carried out at a rate of $V_{per\ A}$. From point B to point A it is necessary also to transmit an information flow with parameters C_B, γ_{C_B}, q_B and γ_{q_B}, and it is transmitted at a rate of $V_{per\ B}$. Furthermore, the channels make it possible with permissible distortion to receive messages in m transmissions of each message. Under these conditions the longest period for transmission of messages, t_{per}, equals

$$t_{пер_A} = \frac{q_A\left(1+\gamma_{q_A}^2\right)m}{V_{пер_A}}; \quad t_{пер_B} = \frac{q_B\left(1+\gamma_{q_B}^2\right)m}{V_{пер_B}}. \tag{4.5}$$

The utilization of a common radio frequency on a radio route is possible when the following inequalities in the interval and transmission period are achieved:

$$\frac{t_{инт_A}}{t_{пер_B}} > 1 \; ; \quad \frac{t_{инт_B}}{t_{пер_A}} > 1; \tag{4.6}$$

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$$t_{\text{прох}1A-B} + t_{\text{пер}B} \leqslant t_{\text{прох}\text{дA}-B};$$
$$t_{\text{прох}1B-A} + t_{\text{пер}A} \leqslant t_{\text{прох}\text{дB}-A}. \tag{4.7}$$

The following is necessary for the purpose of estimating the feasibility of using radio stations with a common frequency:

1. Calculating the total maximum possible load created by all radio stations, by the equation:

$$y_{\text{общ}} = \sum_{i=1}^{k} y_i, \tag{4.8}$$

where Y_i is the maximum possible load created by a single radio station in the radio network and

$$y_i = q_i\left(1+\gamma_{q_i}^2\right) mC_i\left(1+\gamma_{C_i}^2\right). \tag{4.9}$$

2. Calculating the maximum carrying capacity of the radio network by the equation:

$$Q = 60K_Q V_{\text{пер max}}, \tag{4.10}$$

where $V_{\text{per max}}$ is the maximum transmission rate by radio stations in groups per signal per minute; K_Q is a factor characterizing the level of employment of the radio network and the ability of radio operators to transmit immediately after the end of a receiving transmission with a total value for the duration of pauses (t_{pauz} per min) between transmissions per hour of operation of the radio network of:

$$K_Q = 1 - \frac{\Sigma t_{\text{пауз}}}{60}. \tag{4.11}$$

3. Determining the possibility of operating at a common frequency. Traffic at a common frequency is possible in a radio network with a given number of stations if the following inequalities are fulfilled:

$$\frac{Q}{y_{\text{общ}}} \geqslant 1; \tag{4.12}$$

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$$t_{\text{прох}_д} = t_{\text{прох}_1} + \tau, \tag{4.13}$$

where τ is the waiting period, calculated by using the apparatus of the queueing theory.

If in inequalities (4.6) and (4.12) a number greater than one is gotten, then the excess characterizes, as it were, the carrying capacity potential for the radio route and the radio network. A number less than one indicates the need for carrying out measures ensuring communications.

In radio networks it is possible to assign common operating, receiving and transmitting frequencies, a call frequency and several operating frequencies. Frequencies at which communications are carried out are called main frequencies, and standby frequencies are those which are changed to when it is impossible to carry out communications at the main frequency, e.g., with heavy interference. Frequencies are periodically altered with a change in the conditions for the propagation of radio waves, and also for the purpose of improving the secrecy of communications.

Communications facilities and personnel must be estimated and allocated to take into account the difference in parameters under identical operating conditions and the difference in the skills of communications personnel. The best equipment and specialists are assigned to the more important routes.

In calculating the number of radio receivers and transmitters for a ship, vessel or communications unit, it is necessary to take into account the fact that reception goes on continuously regardless of the incoming flow; therefore, the number of radio receivers (N_{pr}) is equal to the number of channels (S), $N_{pr} = S$. Transmission can be carried out by a single radio transmitter in several communications channels; therefore, the number of transmitters (N_{per}) can be smaller than the number of channels by a factor of K_S, $N_{per} = K_S S$. The value of K_S is determined empirically during a period of extended operation. For ships of foreign fleets, $K_S = 0.5$ to 0.8.

A determination of communications standby facilities for a command level calls for calculation of the required facilities for two-way communications, of operators and of communications data, which must ensure the possibility of replacing equipment which has gone out of order and operators, and of building up communications along the most important routes.

For the purpose of carrying out the transmission and reception of information in a communications system, it is necessary in advance to determine (precisely define) the command levels taking part in control and all communications routes; to make calculations and develop measures for ensuring the reliability, speed, and, when necessary, secrecy along all communications routes of M command levels, and stability of the communications system; to define precisely the system of information transmission in the system; to determine duplicating and bypass routes for the most important command levels; when necessary, to

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to make calculations and develop measures to ensure the secrecy of communications; to determine efficient methods of organizing communications and to form the required number of radio networks and routes with an efficient utilization of facilities and communications personnel, and, for radio communications, of radio frequencies; to determine (establish) communications data and traffic and SES rules in the communications system; and to allocate efficiently the manpower of communications subdivision and to determine standby forces.

Of these measures, let us dwell only on the formation of radio networks and routes in the organization of radio communications, since the remaining problems are solved in a similar manner as when organizing the communications of a command level.

It is advisable to form radio routes and networks in the following manner.

It is necessary first of all to give a representation of the entire traffic of all command levels between which it is necessary to arrange for communications. Let us assume that it is necessary to arrange for radio communications between 10 command levels (a_1 to a_{10}). On the basis of a diagram of information transmission (fig 4.5) and anticipated flows, table 4.1 is drawn up--in groups per unit of time and generally in hours occupied. In the top horizontal line of the table are shown the receivers, i.e., those to whom the information is sent, in the extreme left vertical column, the senders, i.e., those who send it, and at the intersections of lines and columns is shown the number of groups per hour transmitted by a specific sender (vertical column) to a specific receiver (horizontal line). For example, $a_2 \rightarrow a_7$, 20 groups per hour, $a_7 \rightarrow a_1$, 40 groups per hour, etc. In the column next to last are shown the circulating communications for a given sender, which should be received by all receivers.

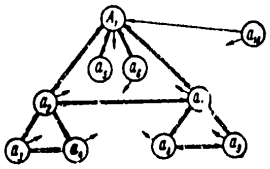

Figure 4.5. Diagram of Transmission of Information Between Command Levels: → Circulating Message Communications

In the last column is given the total outgoing flow from each sender, and in the last line, the incoming flow for each receiver. In the last slot in the last line is shown the total flow of information which must be transmitted between the radio stations in question.

For the purpose of forming radio networks by the method suggested (let us call it the permissible load method), it is necessary to know the permissible load for the network, which depends on the requirements for communications. If

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the requirement of high speed is the major requirement, then in using a common or transmitting frequency it is necessary to determine Q from equation (4.10) and to calculate the permissible load for the radio network, Y_{dop}, by (4.12). It is necessary that the permissible waiting time, τ_{dop}, and t_{prokh} be ensured.

Table 4.1.

1) Отправители	2) Адресаты											
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	$a_{\Sigma 11}$	y_Σ
a_1	0	205	30	30	15	15	50	30	30	0	50	455
a_2	85	0	35	35	0	0	20	0	0	0	10	185
a_3	5	25	0	15	0	0	0	0	0	0	5	50
a_4	5	25	15	0	0	0	0	0	0	0	5	50
a_5	10	0	0	0	0	0	0	0	0	0	0	10
a_6	20	0	0	0	0	0	0	0	0	0	30	50
a_7	40	20	0	0	0	0	0	35	35	0	10	140
a_8	0	0	0	0	0	0	25	0	20	0	5	50
a_9	0	0	0	0	0	0	25	20	0	0	5	50
a_{10}	30	0	0	0	0	0	0	0	0	0	60	90
y'_Σ	195	275	80	80	15	15	120	85	85	0	180	1130

Key:
1. Senders
2. Addressees

If the requirement of secrecy is the main one, then in this case Y_{dop} must be calculated on the basis of the permissible number of transmissions at a given frequency ($n_{per\ d}$). For assigned values of the probability of the detection of transmission ($P_{obn\ d}$), radio interception ($P_{per\ d}$) or radio direction finding ($P_{pel\ d}$), characterizing quantitatively the requirement for secrecy of communications, the value of $n_{per\ d}$ is calculated by the equation:

$$n_{\text{пер д}} = \frac{\lg (1 - P_{i\text{д}})}{\lg (1 - F_{i1})}, \tag{4.14}$$

where $P_{i\ d}$ is one of the assigned (permissible) values of $P_{obn\ d}$, $P_{per\ d}$ and $P_{pel\ d}$, and P_{i1} is the value of this probability for a single transmission. Then is calculated

$$y_{\text{доп}} = (q_{\text{сл}} + q_{\text{загл}} + q_{\text{сооб}})\,(1 + \gamma_q^2)\, n_{\text{пер д}}. \tag{4.15}$$

[Subscript "sl" = word, "zagl" = heading and "soob" = message.]

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If the requirements of speed and secrecy are identical, then the lower Y_{dop} is chosen.

If $Y_{obshch\ [total]} \leq Y_{dop}$, then all radio stations can operate in one radio network at one operating frequency. This is possible with not too great a number of radio stations or with a slight load. If $Y_{obshch} > Y_{dop}$, then communications with individual radio stations is extended into independent radio routes and radio networks. The decisive factors for the formation of an individual radio route are the content and volume of information, and for a radio network, also the mutual interest in the exchange of information between radio stations. Thus, for the information travel diagram (fig 4.5) and information flows (cf. table 4.1) (in groups), we get the following radio networks and radio routes with a load equal to

$$\text{P/п №1} - y_I = y_{1-2} + y_{2-1} = 290 \text{ groups};$$
$$\text{P/c №2} - y_{II} = y_{2-3} + y_{2-4} + y_{3-2} + y_{3-4} + y_{4-2} + y_{4-3} = 150 \text{ groups};$$
$$\text{P/c №3} - y_{III} = y_{7-8} + y_{7-9} + y_{8-7} + y_{8-9} + y_{9-7} + y_{9-8} = 160 \text{ groups};$$
$$\text{P/c №4} - y_{IV} = y_{2-7} + y_{2-11} + y_{3-1} + y_{3-11} + y_{4-1} + y_{4-11} + y_{5-1} + y_{6-1} + y_{7-1} + y_{7-2} + y_{7-11} + y_{8-11} + y_{9-11} + y_{10-1} + y_{10-11} = 250 \text{ groups};$$
$$\text{P/c №5} - y_V = y_{1-3} + y_{1-4} + y_{1-5} + y_{1-6} + y_{1-7} + y_{1-8} + y_{1-9} + y_{1-11} + y_{6-11} = 280 \text{ groups}.$$

It is not difficult to note that the total load of radio networks equals $Y_I + Y_{II} + Y_{III} + Y_{IV} + Y_V = 1130$ groups, i.e., is equal to Y_{obshch}. The information flows formed are shown in table 4.2 and the radio route and networks in the diagram (fig 4.6a).

If for radio communications conditions the permissible capacity of radio networks is $Y_{dop} = 400$ groups, then we will get a smaller number of radio networks. In particular, the following variant can be used:

$$\text{P/c №1} - y_I = y_{1-2} + y_{1-3} + y_{1-4} + y_{1-5} + y_{1-7} + y_{1-8} + y_{1-9} = 390 \text{ groups};$$
$$\text{P/c №2} - y_{II} = y_{2-3} + y_{2-4} + y_{3-2} + y_{3-4} + y_{4-2} + y_{4-3} - y_{7-8} + y_{7-9} + y_{8-7} + y_{8-9} + y_{9-7} + y_{9-8} + y_{2-7} + y_{7-2} = 350 \text{ groups};$$
$$\text{P/c №3} - y_{III} = y_{1-11} + y_{2-11} + y_{3-11} + y_{4-11} + y_{6-11} + y_{7-11} + y_{8-11} + y_{9-11} + y_{10-11} + y_{2-1} + y_{3-1} + y_{4-1} + y_{5-1} + y_{6-1} + y_{7-1} + y_{10-1} + y_{1-6} = 390 \text{ groups}.$$

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The sum of $Y_I + Y_{II} + Y_{III} = 1130$ groups, i.e., is again equal to Y_{obshch} in table 4.1. The radio networks formed in this manner are shown in the diagram (fig 4.6b).

Table 4.2.

1) Отправители	2) Адресаты											
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	y_x
a_1	0	205	30	30	15	15	50	30	30	0	50	455
a_2	65	0	35	35	0	0	20	0	0	0	10	185
a_3	5	25	0	15	0	0	0	0	0	0	5	50
a_4	5	25	15	0	0	0	0	0	0	0	5	50
a_5	10	0	0	0	0	0	0	0	0	0	0	10
a_6	20	0	0	0	0	0	0	0	0	0	30	50
a_7	40	20	0	0	0	0	0	35	35	0	10	140
a_8	0	0	0	0	0	0	25	0	20	0	5	50
a_9	0	0	0	0	0	0	25	20	0	0	5	50
a_{10}	30	0	0	0	0	0	0	0	0	0	60	90
y_x	195	275	80	80	15	15	120	85	85	0	180	1130

Key:
1. Senders
2. Addressees

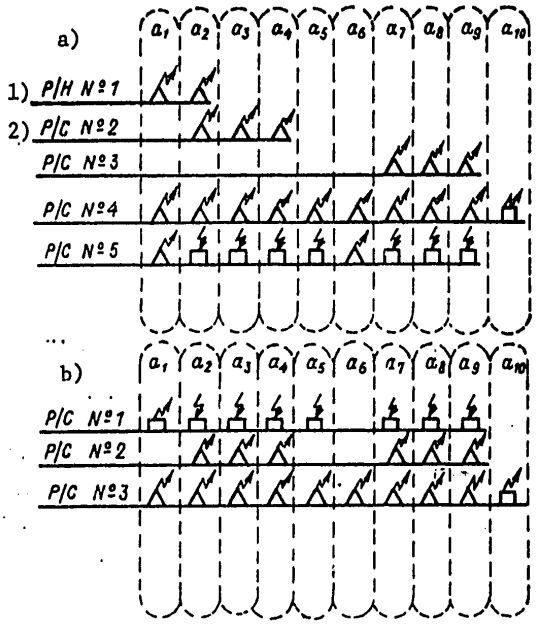

Figure 4.6. Radio Networks and Radio Routes Formed: a--variant I; b--variant II

[Key on following page]

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Key:
1. Radio route No 1 2. Radio network No 2

The following conclusions can be drawn for these variants of the formation of radio routes and radio networks with a variation in Y_{dop}.

1. If the requirements for communications are increased (this is expressed quantitatively by a reduction in Y_{dop}), without taking added measures for providing for these requirements, then this will result in an increase in the number of radio routes and radio networks and, consequently, of radio stations, personnel and radio frequencies employed.

2. When measures are taken to ensure the reliability, speed and secrecy of communications (which quantitatively results in an increase in Y_{dop}), a reduction in the number of radio networks occurs, and, consequently, in facilities, personnel and, possibly, radio frequencies. The latter depends on the procedure used for utilizing radio frequencies and the rate at which they are changed.

3. In forming radio networks it is necessary to provide also for possible increases in information flows in the process of control. By employing tables of information flows, it is possible to add changes to the grouping of information flows and, in keeping with this and the current situation, to alter the structure of the communications system. If the flows or the number of radio stations in the radio network are increased, a solution is found to the problem of segregating from the radio network in question individual radio routes and radio networks. The decisive factor here is the content and volume of information, but it is also necessary to take into account the convenience of control. In particular, vessels or ships which solve a single problem are as a rule segregated into an independent radio network. Sometimes the decisive factor can be the need to fulfill heightened requirements for communications, e.g., for ensuring speed in the transmission of information. If there is a reduction in flows, communications units and routes are united. In the uniting of communications routes, one-way radio communications are organized, and in the uniting of units, a two-way radio communications network (radio route).

4. The radio networks and radio routes obtained must be analyzed in terms of the structure of radio stations and their load for the purpose of uniting them. Thus, if the radio networks are almost of identical structure, then, taking into account the load, it is possible to unite them into a single one. It is necessary always to strive for a minimum of radio routes and radio networks. But it must be remembered that the load, even Y_{chnn}, must not be a limiting load, i.e., in a radio network there should also be a margin for the inclusion of radio stations when utilizing this radio network as a duplicating network with heavy interference or the heavy overloading of another radio network. Here it is obvious that the greater the load in a radio network the more difficult it is to keep secret.

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The formation of radio networks and radio routes is one of the major aspects of planning radio communications, and modifying the structure of radio networks and their modes of operation with changes in circumstances, communications requirements and information flows is an important part of the work of a communications agency in controlling a communications system.

4.4. Basic Rules for the Utilization of Communications

By the utilization of communications is meant the practical employment of facilities, channels and communications systems for obtaining and transmitting information in control and the fulfillment of set objectives.

The right to utilize radio communications on a vessel or ship is had only by the captain, commanding officer, and, in joint sailing operations, the flag officer. On shore this right is enjoyed only by specific officials of the control agency; for example, in a force, the chief of staff. The right to employ visual and other forms of communication is given to other official personnel. However, this personnel cannot always employ all facilities and kinds of communications at their disposal. The employment of communications at sea is regulated by "Marine Mobile Service Radio Communications Guide" [61], radio communications regulations, telegraph and telephone regulations, and also other resolutions adopted by international conferences. The employment of radio communications with Soviet vessels is regulated by rules for radio communications and other supervisory documents of the appropriate ministry [53, 54], and, with ships of the Soviet VMF, by manuals, guides and instructions on communications, and by orders from headquarters and staff orders regarding communications. These supervisory documents take into account the regulations and requirements of international agreements.

The employment of communications is not infrequently taken in the narrow sense, as the employment of communications facilities and channels. In the broad sense it covers the employment of communications facilities and channels, the regulation of the employment of communications by subordinate command levels and officials, and the creation of the necessary or most favorable conditions for the accomplishment of communications. The employment of communications combines the operations of official personnel participating in control and the operations of communications personnel making control possible, which must be clearly defined and coordinated and must make up a unified complex.

The utilization of communications facilities and channels includes the preparation of a message for transmission through communications facilities and the transmission of this message in a communications channel.

The preparation of a message for transmission through communications facilities is performed by the person issuing the message and the communications service specialists on duty or in charge who have received this message, and generally includes the following: a) selection from the complex of communications facilities and types prepared of those which most completely ensure the required quality of communications under specific conditions of circumstances;

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b) the writing of the message, which must be clear, distinct and as concise as possible, and the formulation of it on a blank; c) addressing of the message, i.e., a precise indication of where it is to be sent and to whom it is to be given; d) when necessary, an indication of the urgency of the message in its transmission, processing and delivery. In naval communications, the urgency of a message is customarily indicated by a so-called series, written down to indicate the content of the message and its importance; e) an indication of the method of exchange in transmission of the message (acknowledgement, confirmation of receipt, reciprocal verification). The Americans, for the purpose of secrecy of the location of a radio station, employ the methods of radio broadcasting (without acknowledgement) and radio interception.

The preparation of a message for transmission can include other operations also: For example, for the transmission of a message through retransmission points, it is necessary to indicate these points (the message's route).

The transmission of a message through a communications channel is performed by a communications operator or the person responsible for calls, who generally performs operations relating to switching on and tuning communications facilities, the establishment of communications with the reception point, service calls and transmission of the message.

The regulation of the utilization of communications is aimed at the most effective utilization of a communications system by all command levels and officials by means of the coordination of the operations of all personnel and the regulation of information flows, the transmission of messages and the making of calls with respect to direction and volume, and other questions relating to the utilization of communications. For example, a radio communications regulation [61] forbids all radio stations to make unnecessary broadcasts and to transmit superfluous signals or pieces of correspondence. The documents regulating international communications clearly define the utilization of frequencies and types of transmission, call letters, station operation hours and priority, selective calling in the marine mobile service, etc.

Regulated especially strictly is the procedure for employing communications and the transmission of distress, alert, urgency and security signals. These same documents obligate all who carry out communications to maintain secrecy.

The employment of communications with vessels is regulated by ministries and ship owners and with ships, by the headquarters of a fleet and forces, i.e., those who control vessels and ships. The control agency, for purposes of regulating the carrying out of communications, must determine the following:

1) The procedure for employing communications in a port, harbor, roadstead, in a crossing, in areas of operation and in returning. Here a distinction is made between the procedure for solo and joint navigation and for performing objectives. Usually this procedure implies the right to employ long-range and intrasquadron communications, the sequence for the employment of communications facilities, etc.

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2) The procedure for reports and notifications, i.e., who must report and notify, when, to whom, regarding what and with what facilities.

3) The operating modes of the communications system, which are ordinarily determined in relation to communications routes, radio networks, and radio routes for various periods of operations. The mode includes the type of operation and the time of operation.

4) Measures for ensuring preservation of the secrecy of the content of transmitted messages and calls, which include coding of the text, i.e., the substitution by means of special tables (codes) of the ordinary open text with symbols, and the utilization of coded charts. In the opinion of foreign specialists, the best result is provided by employing automatic classifying equipment and the line coding equipment designated for telegraph communications channels. For telephone communications it is possible to use equipment making a telephohe message unintelligible to listeners [39, 60, 66, 68].

For the purpose of utilizing communications by ships in combat operations, staffs also develop measures for concealing indications of decamouflaging in carrying out communications, i.e., measures included in radio camouflaging; measures for communications maneuvers for the purpose of creating the most favorable conditions for communications and protecting from enemy reconnaissance and radio interference and the influence of nuclear explosions; and the employment of communications standby facilities. These questions, in spite of their importance and significance, are not considered here; the reader can refer to naval literature containing these questions, e.g., [39, 66-69].

The creation of the required or most favorable conditions for carrying out communications includes operations by the operator, e.g., the employment of a directional reception system for the purpose of improving the quality of reception of a remote radio station, and operations by the captain and commanding officer, e.g., the surfacing of a submarine for radio reception or radio transmission. The highest need for creating these conditions arises in the employment of hydroacoustic communications and in radio communications with submarines and airplanes.

The utilization of communications under modern conditions requires high training on the part of captains, commanding officers and officials of control agencies and the communications service.

Section Two

Communications with Craft and Ships

Chapter 5. Equipment of Craft and Ships with Communications Facilities

The effectiveness of communications with craft and ships is determined primarily by communications facilities and their qualitative and quantitative structure and their proper distribution, i.e., by the equipment.

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5.1. Fundamentals of Equipping Craft and Ships with Communications Facilities*

A ship or a vessel is regarded as a unified complex system, in which are segregated in relation to their functional traits, subsystems, such as the hull, power plant, steering equipment, arms, electronic equipment, navigation equipment, communications equipment, etc. The communications system of a modern vessel includes different communications facilities, such as a radio (microwave, HF, MF and VLF), satellite, hydroacoustic, visual, and audio. Helicopters and boats can be employed as mobile communications facilities. As an example, in fig 5.1 is shown the communications system of a U.S. Navy antisubmarine vessel [15].

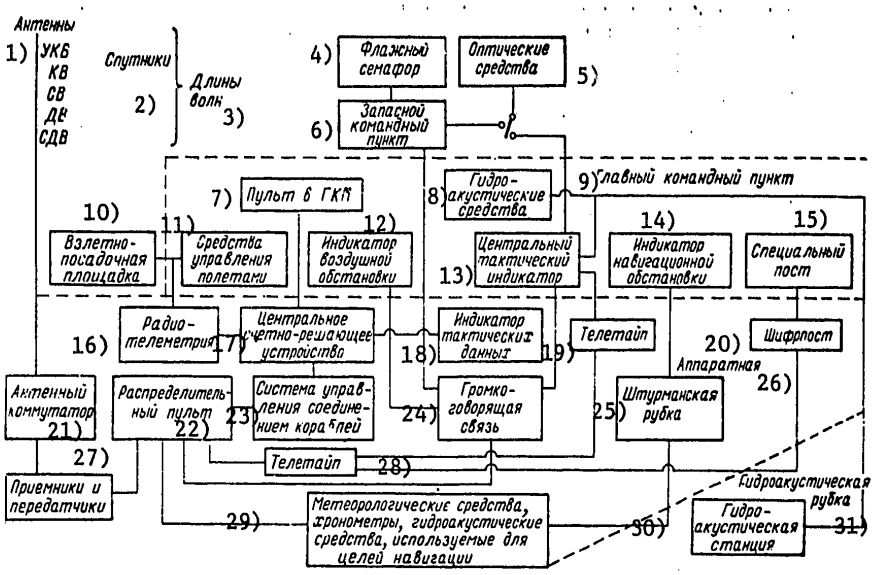

Figure 5.1. Communications System of a U.S. Navy Antisubmarine Vessel [Key on following page]

*In the VMF communications facilities are a type of armament; therefore it is customary to speak of the arming of ships with communication facilities. However, for convenience in presentation of material, the authors have adopted the term "equipment" in common for craft and ships, as it is also employed, e.g., in the article "Marine Radio Equipment and Ship Radio Equipment," BSE [Great Soviet Encyclopedia], second edition, vol 41, p 228.

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Key:

1. Antennas: microwave, HF, MF, LF and VLF
2. Satellites
3. Wavelengths
4. Flag semaphore
5. Optical equipment
6. Standby command point
7. Console to GKP [main command post]
8. Hydroacoustic equipment
9. Main command post
10. Takeoff and landing strip
11. Flight control equipment
12. Air situation indicator
13. Central tactical indicator
14. Navigation situation indicator
15. Special post
16. Radio telemetry
17. Central computer
18. Tactical data indicator
19. Teletype
20. Code post
21. Antenna commutator
22. Distributing board
23. Ship formation control system
24. Loudspeaker communications
25. Chart house
26. Instrument room
27. Receivers and transmitters
28. Teletype
29. Meteorological equipment, chronometers and hydroacoustic equipment used for purposes of navigation
30. Hydroacoustic station
31. Hydroacoustic room

For the purpose of solving problems relating to equipping a vessel with communications facilities at the planning stage, it is necessary to perform the following types of operations in the sequence indicated:

1. Establishment of the need for information in the solution by a vessel or ship of major and secondary objectives, and for the purpose of navigation safety, i.e., the communications route--with whom one-way communications (the reception or transmission of information) and two-way (information exchange) must be established.

2. The determination of the information requiring reception or transmission in the fulfillment by a craft or vessel of its objectives in relation to purpose (reporting, ordering, notifying), and in relation to types (telephone, telegraph, printing, facsimile telegraph, etc.) and the characteristics of information flows (their quantitative parameters) on all communications routes.

3. The calculation of the required communications range on each route, on the basis of the proposed areas of navigation of the craft or ship.

4. The determination of the required quality of communications on all communications routes in the transmission (reception) of specific information flows (with respect to reliability, fidelity, speed, and, when necessary, the secrecy of communications).

5. The determination of a craft's or ship's requirements for communications facilities resulting from navigation conditions, with regard to the duration of operation, temperature conditions, moisture resistance, mechanical strength, vibration, pressure on antennas, etc.*

*Modern vessels and ships must as a rule withstand navigation in Arctic and tropical areas of the global ocean.

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6. The coordination of the position of the vessel's or ship's communications system in existing (planned) tactical communications systems of ships (of a group or force), of a group of vessels (squadrons, flotillas, and MRKh vessel expeditions) and of the communications of vessels and ships with the shore (the PU, from which control is carried out), and also the determination of the need for and the possibility of the utilization of international radio communications, in particular, the reception of hydrometeorological notices, distress and alert signals, etc. The development of an arrangement for communications of a ship or vessel when sailing in proposed areas and fulfilling its key and secondary objectives under the anticipated conditions of the situation. Here main and standby variants of message travel should be provided for, i.e., in addition to direct communications channels, bypass channels via retransmission and radio relay points.

7. The formation on the basis of the work performed above of a structure for craft and ship communications facilities in terms of quantity and quality (radios, hydroacoustic, visual and audio, etc.).

8. Determination of the structure of communications posts and radio centers and of their relative location on a ship and vessel, the distribution of communications facilities by communications posts and radio rooms and radio receiving and transmitting centers, and determination of the constitution of receiving and transmitting antennas, taking into account requirements for electromagnetic compatibility and requirements with regard to levels of radiation dangerous to the munitions of ships and dangerously explosive cargo of vessels.

9. The development of a plan for the distribution of communications facilities and auxiliary equipment within communications posts, radio rooms and radio centers, taking into account electromagnetic compatibility and protection of personnel from the effect of radio waves, as well as of remote communications posts, terminal equipment at the command point and in other service areas of the vessel.

10. The development of a system of loudspeaker and intraship communications, and determination of the location of and equipment for the command relay unit of a vessel or ship.

11. The solution of problems relating to the switching of communications facilities, controlling them and monitoring their operation.

12. The coordination of the operation of communications facilities and equipment, especially in simultaneous operation of transmitting and receiving equipment, and of electromagnetic compatibility with the operation of radio navigation, radar and other radioelectronic equipment of the vessel or ship, and the precise determination of the composition of communications facilities from the quantity and quality standpoint, and of their location.

The planning of equipment with external and internal communications facilities should provide for a careful consideration and solution of problems relating

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to the containment and monitoring of electromagnetic radiation and noise, as well as to protection from them. The equipment should possess high reliability and repairability and guarantee round-the-clock operation during the sailing period and its restoration without a long search for damage.

This procedure should be obligatory, as concerns the basics of equipping with communications facilities and complexes ships and flagships of squadrons and commercial fleet expeditions.

For passenger, cargo and other sea vessels, worldwide practice has developed rules for radio equipment which have been accepted by international conventions [58]. According to these rules, the basic radio communications facilities are divided by purpose into main, standby (emergency) and operating.

Main radio communications facilities must make possible the reception and transmission of messages transmitted by distress, alert, urgency and safety signals, of messages regarding emergencies, of navigation warnings, of weather forecasts, of medical advice, and also the reception of time signals. It is permitted to use main radio communications facilities for the transmission and reception of service and special correspondence.

Standby radio communications facilities serve the purpose of transmitting and receiving information during distress of a vessel, as well as in other cases when the utilization of main radio communications facilities becomes impossible.

Operating radio communications facilities serve the purpose of receiving and transmitting messages of an operating nature, as well as emergency and special correspondence.

The communications facilities of a vessel are distributed in the following manner: visual--at signal posts; hydroacoustic--in hydroacoustic rooms; satellite--at satellite communications posts, and the control consoles for them--in radio rooms; and radio facilities--in radio rooms (main and standby). On large ships radio communications facilities are located in receiving and transmitting centers, and the command relay unit at a relay post.

On all vessels the main radio room should be located on the deck of the fore bridge or higher, in the vicinity of the point from which the vessel is steered, preferably portside. In individual cases, when the dimensions of the fore bridge make it possible to place on it only the chart room and wheelhouse, it is permissible to locate the radio room at one deck below the fore bridge [58]. Here it is necessary to see to the following: the lead-in of antennas into the radio room directly from outside; minimal length of the route for laying cables leading to the machine, battery, and chart room; maximum distance of antennas from large projecting metallic objects (pipes, masts, fans and the like); maximum distance of the radio room from electrical equipment and lines, as well as from equipment and areas which release a considerable amount of heat and produce noise; and the best conditions for the proper location of radio equipment and the work and safety of personnel.

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The location of the radio room on a vessel should be such that the installation and passage through it of equipment not related to communications facilities are excluded. Furthermore, the radio room is located adjacent to the cabin of the radio station chief. The radio room must have an emergency exit. The area of the radio room should be no smaller than twice greater than the area occupied by radio equipment and furnishings in the plane, and its height, not less than 2 m. The partitions, deckheads and doors of the radio room should be covered on the inside with sound and heat insulation made of fire-resistant materials. The insulation and sheathing are totally covered with sheet metal. The level of mechanical noise in the radio room created by external sources under operating conditions must be reduced to 65 dB.

On each vessel on which radio equipment is installed, in addition to radio rooms and radio centers, it is necessary to provide also for a machine room (if there are electrical machines and transformers) and a battery room. On large passenger vessels it is recommended that there be an emergency radio room, as well as a separate post for the reception of radio messages from passengers.

All the equipment of standby (emergency) radio communications facilities should be located on the vessel in such a manner that its ability to operate is not impaired when the vessel is submerged to the level of the deck of the radio room.

On ships radio communications facilities are located at receiving and transmitting centers and communications command posts. The communications command post is located near the ship's command station, and radio receiving and transmitting centers, in individual areas, taking into account ensurance of their stability.

For the purpose of determining the standard structure of radio equipment, all sea vessels for long-distance navigation are divided into three groups: 1) passenger and all cargo vessels weighing 1600 registered tons and more; 2) cargo vessels weighing 300 registered tons and more, but not less than 1600 registered tons [as published]; 3) cargo vessels with a displacement of less than 300 registered tons.

In keeping with the rules for conventional equipment, on each vessel of these groups standard (minimal) equipment must be installed in conformity with the USSR Registry [58]. In addition to the equipment indicated, it is recommended that sound recording equipment be installed, along with radio telephone receivers for the listening watch, and automatic receivers for radio telephone alert signals. It is recommended that ships intended for transporting more than 199 people (including the crew) be equipped with high-speed equipment and equipment for the reception of facsimile telegrams.

On each vessel of the third group intended for sailing not more than 20 miles from the point of assignment, in the effective area of coastal radio telephone stations carrying out a continuous round-the-clock listening watch at the

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international call and security frequency of 156,8 MHz, it is permitted to use a stationary or mobile VHF radio telephone station.

On each ship designed for sailing at a distance from the place of refuge of more than 20 miles and for transporting more than 199 people (including the crew), in the radio room two work areas must be provided for making it possible to carry on radio traffic with the main and operating facilities simultaneously.

Commercial vessels to be conveyed to a point of trade employing the decks of depot ships or other vessels must be furnished with communications facilities as are ships of the third group.

Non-self-propelled vessels designed for towing at sea or for extended anchorage outside the water area of ports or roadsteads, having people on board, also must be equipped with radio communications facilities as are vessels of the third group, for making possible in the first case communications with the towing vessels, and in the second with the nearest coastal radio station.

On tankers, the power of transmitters at the carrier frequency should not exceed 500 W in the antenna, whereby the peak power of the transmitter should be not greater than 1000 W.

On each vessel, for the purpose of making it possible to power radio equipment and at the same time to charge batteries, provision is made for the supply of electric power from a marine electric power plant, whereby the variation in voltage should not be greater than $\pm$ 10 percent of the rated, and in a.c. frequency, not greater than $\pm$ 5 percent of the rated.

In all instances when the employment of a ship's electric power plant as the key power source for radio equipment is impossible, it is permitted to use storage batteries, ensuring continuous operation of the transmitter for not less than 6 h, and of receivers for not less than 24 h.

Standby (emergency) batteries are used as a source of electric power for standby (emergency) radio communications facilities, and they must guarantee a continuous power supply for at least 6 h for the standby (emergency) transmitter and receiver, the automatic transmitter of radio telegraph alert and distress signals, lamps, and the portable inspection lamp.

In keeping with the rules for the conventional equipment of sea vessels, radio telegraph communications facilities of a vessel include the following: the main radio telegraph transmitter and radio receiver; the standby (emergency) radio telegraph transmitter and radio receiver; the automatic radio telegraph alert signal transmitter and receiver; the operating transmitter and receiver; a portable radio set for rescue apparatus; a radio set for the lifeboat, and an emergency radio buoy. The emergency radio buoy indicates the position of the vessel, facilitating the work of search and rescue groups. It is placed on the vessel's open deck in such a manner as to remain floating in case the vessel sinks. Having come to the surface, the radio buoy transmits type A2 or A2N signals at a frequency of 2982 kHz for 48 h.

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The radio telephone communications facilities of a vessel include the following: the main radio telephone receiver and transmitter; the standby (emergency) radio telephone receiver and transmitter; an automatic transmitter and receiver for radio telephone alert signals; a radio telephone listening watch receiver; a loudspeaker with a filter; and a VHF radio telephone set.

On modern large passenger vessels and research vessels it is possible to install a multichannel printer for HF radio communications, as well as for telephone communications, utilizing single-band improved-reliability radio telephone communications lines of the "Linkompeks" type. An example of a block diagram of such an HF radio communications line is shown in fig 5.2 [47]. For the purpose of clarity, in this diagram are shown a transmitter and receiver which have four independent telephone channels (A_2, A_1, B_1, B_2). Signals are supplied by the high-frequency telegraph channel to input A_2 of the transmitter from the telephone channel multiplexing unit. Channel A_1 is used to transmit telephone messages in analog form without measures for improving noise immunity. Channel B_1 is used for transmitting these same messages in analog form, but in this case at the input of the transmitter and the output of the receiver is connected a "Linkompeks" unit, which improves the noise rejection of telephone communications through this channel. Facsimile telegraph information is transmitted through channel B_2.

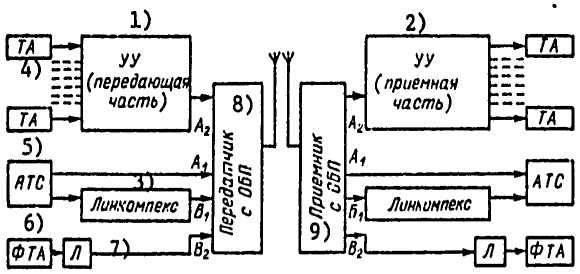

Figure 5.2. Example of Block Diagram of Modern HF Radio Communications System for Vessels

Key:

1. UU [multiplexing unit] (transmitting half)
2. UU (receiving half)
3. "Linkompeks"
4. TA [telegraph equipmant]
5. ATS [dial telephone exchange]
6. FTA [facsimile telegraph unit]
7. L [line]
8. Transmitter with OBP [single sideband]
9. Receiver with OBP

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Rules provide for equipment with command relay facilities, which must make possible the transmission of service commands from microphone posts into all living and public areas, as well as to posts on the vessel's open deck, with audibility such that the level of the reproduction volume exceeds the noise level by 20 dB. On each passenger vessel there must be provided no less than three main relay lines: a deck line, a service line and a passenger line. On ships is installed the "Ryabina" unified loudspeaker communications equipment.

The importance of intraship communications is steadily increasing, and at the present time two thirds of the crew simultaneously use intraship communications facilities.

In the U.S. Navy, since 1963 work has been begun on the integration of ship networks and communications lines into a single system. An experimental unified intraship communications system--the AICS--has been developed and successfully passed tests, for all kinds of communications (telephone, printing, loudspeaker, digital and vocoder). It includes two separate commutators (in the bow and stern of the ship), intercommutator cables, and user units for external communitions channels and the ship relay network. The commutator is designed to serve 120 networks. For the purpose of calling a network, its number is transmitted, and the location of a user in the system is determined by three-digit numbers. The reliability of this system is ensured by duplication of major units with standby units which are automatically turned on.

In France the creation of intraship communications with delta modulation has been provided for vessels and ships. Digital communications eliminates the laying of cables for different purposes (telephone, loudspeaker networks, etc.) and makes it possible to do without cumbersome and complex filters, which are necessary when using analog systems of communication with frequency multiplexing of channels. The new system is designed to serve 800 users. It connects all intraship users with a coaxial cable, with an operating speed of up to 11 Mbits/s.

The small overall dimensions and weight of fiber optics cables and their flexibility in laying have made it possible for the U.S. Navy to attempt to install systems for transmitting data through fiber optics cables on board vessels, surface ships, submarines and airplanes. In addition, fiber optics cables do not radiate electromagnetic waves, and, consequently, do not create noise and exclude the overhearing of conversations. In the U.S. Navy plans are being made to replace closed-circuit television cables and then to install a telephone communications system using fiber optics, on ships.

For standby intraship communications, the opportunity is provided of utilizing miniature portable microwave radio sets.

A main and standby antenna should be installed on each vessel. By means of a special switch or commutator each of them is connected to any transmitter or receiver (main, standby or operating). The connection of the main antenna to the operating transmitter and receiver does not have to be provided if

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other no less effective antennas are connected to them. If the ship has a standby main antenna which is completely ready for immediate raising, then a standby (emergency) antenna does not have to be installed. An individual antenna, or if this is possible, a standby (emergency) antenna is used for ensuring the normal operation of the operating transmitter on a ship.

On ships of the first and second groups are installed not less than two receiving antennas for the purpose of ensuring reception at any two receivers simultaneously--main, standby or operating. There must be special individual antennas for the automatic alert signal receiver and the audio communications radio telephone receiver. A common antenna can be used for radio broacast receivers. The makeup and types of receiving antennas depends specifically on the number of marine and ship radio receivers of all kinds, which varies from a few on cargo vessels to a few dozen on large passenger liners [10], and on ships, e.g., on American communications and relay ships, reaches 50 to 60.

For global marine communications the installation of satellite communications systems equipment is provided.

Hydroacoustic communications facilities [56] are installed on surface vessels for communications with submarines, and on MRKh vessels, with deeply submerged equipment by means of which studies are made of supplies of fish in the global ocean.

Top lights for signal communications are installed on ships of the first group in the following manner: the front one on the foremast or in front of it, and if the ship does not have a foremast, then on its bow section in the diametrical plane at a height of not less than 6.1 m above the ship's hull; and the rear top light, on the mainmast at a height higher than the front one by not less than 4.57 m . If a signal light is installed on a ship whose length is less than 45.75 m, it must be at a height of 6.1 m. Also used on ships and vessels is a spotlight for visual communications.

For sound signaling on vessels is employed sound signaling equipment (bells, a gong or a siren). They must be positioned so that no parts of the structure or equipment of the ship create sound interference and reduce the force and frequency of the sound.

5.2. Requirements for Vessel and Ship Communications Facilities; Key Technical Characteristics of Facilities and Antennas

The following are the general operating equipment requirements for new radio equipment for marine vessels:

All radio equipment must possess sufficient reliability and repairability.

All communications equipment, antennas, cables and connection equipment must be designed to operate under any conditions for the operation of sea vessels and ships, and also pass mechanical and climate tests.

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Equipment, depending on its place of installation, must have an appropriate design ensuring sufficient protection of its internal parts from mechanical damage and contact with water. Equipment located in rooms must be sprayproof, and radio equipment installed on an open deck must be waterproof. Portable radio sets for rescue equipment in the open state are made airtight. The standards for shockproofness, shock resistance and vibration resistance, airtightness, and heat resistance, etc., are listed in rules for conventional equipment for sea vessels [54].

The following are general technical requirements for the radio facilities of a vessel:

High stability of the frequency of transmitters and radio receivers ($1 \cdot 10^{-5}$ to 10^{-6} and higher).

The passband for audio frequencies for receivers in AZN, AZA and AZJ transmission should be 350 to 2700 Hz with a permissible variation in amplitude not greater than 6 dB.

The depth of modulation of the transmitter should be not less than 80 percent, and radio telegraph transmitters must ensure the transmission of Morse signals to 200 characters per minute.

Frequency retuning must be accomplished in no more than 5 s (for emergency transmitters) and no more than 15 s for radio communications facilities for other purposes.

In single-band radio lines in A2N, AZA, AZN and AZJ transmission, it is necessary to employ the upper sideband, with corresponding suppression of the carrier frequency.

A new complex of facilities for single-band radio communications has been created and has been widely introduced for USSR MMF and MRkh vessels. The equipment of this complex possesses a number of advantages: high frequency stability, ensuring scan-free and frequency-trim-free radio communications; a great number of types of transmission, making it possible to use the most stable of them; and the employment of semiconductor devices, improving the reliability, reducing the overall dimensions and weight of equipment, and reducing the consumption of electric power.

With this new marine communications complex is accomplished automatic control from the operator's console, and reliability in the operation of new communications facilities is ensured in tropical conditions because of the employment of special materials and coatings, as well as because of the complete hermetic sealing of units. The new marine radio communications complex includes the "Musson," "Brig," "Korvet" and "Bark" radio transmitters and the "Shtorm," "Shtil'," "Sibir'," etc. radio receivers.

The "Musson" radio transmitter is installed on vessels of the maritime and commercial fleet as the main (navigation) MF radio transmitter. It consists

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of three structurally complete blocks: a radio transmitter, a matching unit (SU) and a remote control console (PDU). The radio transmitter enables operation with transmission of A1, A2N and APS (automatic aircraft homing) types at seven fixed frequencies. The control of triggering and tuning units is automatic. Readiness for operation is practically instantaneous. The time for retuning to any frequency is not longer than 5 s. The matching unit enables matching of the antenna's impedance with a high-frequency cable, has an internal antenna commutator, and is installed directly at the lead for the main antenna.

The "Brig" and "Korvet" radio transmitters are designed for marine transport and commercial vessels as operating HF transmitters. They are made out of semiconductors (electron tubes only in the output stage). Control of triggering and tuning units is totally automatic. Each unit consists of three structurally complete blocks: a radio transmitter, a remote control panel (PDU) and a microtelephone with an amplifier. The radio transmitter enables operation with transmission of AZJ, AZA, AZN, A1, A2N, OFT [relative phase telegraphy] and F1 types. Operation is possible with a broadband antenna with a traveling wave coefficient of not less than 0.3 in the HF band. The microtelephone with an amplifier enables single-band telephone operation and controls the transmission of the radio transmitter with a transmitter cutout switch and an automatic selector switch which is installed at a distance of up to 150 m from the transmitter.

The presence of a PDU in the set of a "Musson," "Brig," or "Korvet" transmitter makes it possible to locate the radio transmitter and SU in any unattended area of a vessel at a distance of up to 150 m from the operator, and also to observe variation in current in the antenna and to exercise general supervision.

The key technical characteristics of these new marine radio transmitters are shown in table 5.1.

The "Shtorm-III" radio receiver is designed for use on vessels as the main (navigation) and operating communications receiver. It has a wide frequency range (LF, MF and HF), high sensitivity and immunity of the receiver's input from harm from a high-frequency voltage of up to 100 V. It makes it possible to receive with headphones and a loudspeaker and has an output for a printer. The types of transmission it receives are A1, A2, A3, AZJ, AZN, AZA, F1 and F4. The receiver is made from semiconductors and consists of four structurally complete blocks: a radio receiver (BRP), a frequency stabilization block (BSCh), a frequency telegraphy block (BChT) and a power supply. The independent employment of blocks is provided for: the BRP block (the "Shtorm-I" receiver), a combination of the BRP and BSCh blocks (the "Shtorm-II" receiver) and the BRP, BSCh and BChT as a total unit (the "Shtorm-III" radio receiver). The BSCh and BChT blocks are installed directly in the radio reception block and make up a single whole along with it.

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Table 5.1.

№ пп	1) Технические характеристики	2) Тип передатчика		
		3) «Муссон»	4) «Бриг»	5) «Корвет»
1	6) Диапазон частот (в полосах морской подвижной службы), кГц	7) фиксированные частоты: 410, 425, 454, 468, 480, 500, 512	I 1605—3800 II 4063—25600	I 1603—3800 II 4063—25600
2	8) Сетка частот, Гц	—	11) 100	100
3	Выходная мощность на нагрузке 75 Ом, Вт 9)	нагрузка 10) 2.2 Ом 500 пФ, 200	I диапазон—400 II диапазон—1500	300
4	12) Максимальное отклонение частоты, Гц	$200 \cdot 10^{-6}$	15	15
5	Напряжение питания (от сети переменного тока), В 13)	220/380	220/380	220/380
6	Потребляемая мощность, кВ·А 14)	не более 1	7	3
7	Габариты, мм: 15)	21)		
16	радиопередатчика	1000×512×328	1760×616×340	1760×616×340
17	пульта дистанционного управления	140×338×195	155×338×238	155×338×238
18	микрофона с усилителем	20) согласующее устройство 607×578×330	132×266×120	132×266×120
8	Масса, кг: 19)			
16	радиопередатчика	112	350	350
17	пульта дистанционного управления	6	7	7
18	микрофона с усилителем	20) согласующее устройство 47	3	3

Key:

1. Technical characteristics
2. Type of transmitter
3. "Musson"
4. "Brig"
5. "Korvet"
6. Frequency band (in marine mobile service bands), kHz
7. Fixed frequencies
8. Frequency net, Hz
9. Output power with 75 Ω load, W
10. Load, 2.2 Ω, 500 pF, 200
11. Band I
12. Maximum frequency deviation, Hz
13. Supply voltage (from a.c. line), V
14. Power requirement, kV·A
15. Overall dimensions, mm
16. Radio transmitter
17. Remote control console
18. Microphone and amplifier
19. Weight, kg
20. Matching unit
21. Not more than 1

The "Sibir'" radio receiver is intended for employment on vessels as an operating receiver. It consists of a radio receiver and a PDU. The radio receiver is made out of semiconductors, employing micromodules and integrated circuits. The receiver's input is immune from harm from high-frequency voltage up to 100 V. The receiver has outputs for headphones, a loadspeaker, a printer and facsimile telegraphy equipment and a tape recorder. Types of transmission received are A1, A2, A3, A2N, AZA, AZJ, A7A, A7J, A4, F1, F4 and F9. The

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PDU makes it possible to control tuning and types of the receiver's operation at a distance of up to 50 m.

The key technical characteristics of marine radio receivers are indicated in table 5.2.

Table 5.2.

№ пп	11) Технические характеристики	12) Тип радиоприемника			
		13) «Шторм-I»	14) «Шторм-II»	15) «Шторм-III»	16) «Сибирь»
1	Диапазон частот, кГц	12—30.000	12—30.000	12—30.000	1500—29999
2	Точность установки частоты с БСЧ, Гц	100	100	100	10
3	Суточная стабильность частоты с БСЧ, Гц	20	20	20	$1 \cdot 10^{-7}$
4	Чувствительность в режиме А1 (сигнал/помеха = = 20 дБ), мкВ	2—8	2—8	2—8	1,2
5	Избирательность, дБ	60	60	60	80
6	Ширина полосы забития в диапазоне 1,5—30 МГц, % при помехе 3 В при помехе 30 В	5 10	5 10	5 10	5 10
7	Напряжение питания (от сети переменного тока), В	127/220	127/220	127/220	220
8	Потребляемая мощность (наибольшая), Вт	150	250	250	260
9	Габариты, мм	610×580×280	610×580×460	610×580×650	510×415×500
10	Масса, кг	60	95	125	103

Key:

1. Frequency band, kHz
2. Accuracy of setting frequency in BSCh, Hz
3. 24-h stability of frequency with BSCh, Hz
4. Sensitivity in A1 mode (signal-to-noise = 20 dB), μV
5. Selectivity, dB
6. Penetration bandwidth in 1.5 to 30 MHz band, %, with noise of 3 V, with noise of 30 V
7. Supply voltage (from a.c. line), V
8. Power requirement (maximum), W
9. Overall dimensions, mm
10. Weight, kg
11. Technical characteristics
12. Type of radio receiver
13. "Shtorm-I"
14. "Shtorm-II"
15. "Shtorm-III"
16. "Sibir'"

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The "Chayka-S" single-band radio telephone set is used as the main radio telephone set on sea vessels of the second and third groups, as well as as an additional set on vessels of the first group. It makes possible scan-free and frequency-trim-free telephone communications between a vessel and the shore and between vessels. This radio set is designed according to the "quartz-wave" principle, utilizing single-band modulation. It is made with semiconductors and consists of three blocks: a transceiver, an automatic matching unit (SAU) and a PDU. The receiver and transmitter have 18 strictly fixed frequencies. The frequency band is 1.6 to 8.8 MHz. The transmitter's ouput power is 60 W, and the receiver's sensitivity is not worse than 5 μV.

The "Lastochka" single-band radio set is installed as a standby (emergency) set on vessels where the main means of communication is a radio telephone, as well as as the main radio set on certain MRKh vessels. Depending on operating conditions and purpose, it comes as a unit in two variants: without a 500 block for traffic control communications, and with a 500 block for operation as an emergency communications facility. The output power of the transmitter in the HF band is 15 to 25 W, and in the 500 kHz band, 12 to 20 W.

In addition to HF radio communications facilities, on vessels are installed microwave radio sets of the "Akatsiya," "Grafit," "Seyner," "Reyd" and "Prichal" types, and at coastal radio centers and posts, the "Port-3," "Kama-R" and "Reyd" microwave radio sets, enabling communication with vessels.

The "Grafit" radio set is designed for telephone traffic between vessels and the shore and between vessels. It has quartz frequency stabilization, enabling scan-free entry into communication. A remote frequency setting system with a PDU makes it possible to tune to any of 601 frequencies or to select one of 20 pretuned frequencies.

The "Seyner-1" radio set is designed for low-tonnage vessels. It enables scan-free and trim-free communications with scanning (monitoring) in the reception mode through two communications channels, an operating channel and a safety channel with guaranteed priority. This radio set is made out of semiconductors and employs integrated circuits and microcircuits. It consists of a transceiver and line and battery power supplies. The power of the transmitter is 8 W.

The "Kama-R" radio set is a control set and is made in three variants: the "Kama-R" with a 300 to 300.5 MHz and 336 to 336.5 MHz band and 16 channels, the "Kama-R_2" with a 300 to 300.2 MHz band and five channels, the "Kama-R_3" with a 336 to 336.2 MHz band and five channels. The power of the transmitter is 7 W. The sensitivity of the receiver is 1.5 μV. The power requirement is 200 V·A.

The "Prichal" radio set is a portable piloting set. Frequency band of 156.3 to 158 MHz on four channels. Power of transmitter, 1 W. Overall dimensions, 197 X 108 X 64 mm; weight, 2.2 kg. It is employed in mooring a vessel and in lowering boats into the water.

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The "Port-3" radio set is made in three communications variants for simplex communications ("Port-3S"), duplex ("Port-3D") and radio relaying ("Port-3R"). In this radio set provision has been made for the ability to connect an automatic terminal unit and the coding unit of a selective call instrument of the "Selektor-II" type, etc., as well as for connecting urban and port ATS users for the purpose of hooking up vessels with these networks.

The "Reyd" radio set is designed for telephone communications with vessels and for simplex and duplex radio communications with the shore, including with users of a port or urban ATS. Control is possible from one or two consoles installed at a distance of up to 100 m from the transmitter.

The "Priboy-UM" microwave radio set is provided for communications between vessels and the crew of an airplane or helicopter in an emergency or making a forced landing on vessels.

The key technical characteristics of microwave radio sets are given in table 5.3.

Table 5.3.

1) Технические характеристики	2) Тип радиостанции				
	3) Графит	4) Сейнер	5) Рейд	6) Порт-3	7) Прибой-УМ
8) Диапазон частот, МГц	100—150	156,3—158	156—162	9) 156—158 (Порт-3) 160—162 (Порт-3Д)	121,5
10) Число каналов связи	20 (601)	7	78	4	1
Разнос частот между каналами, 11) кГц	50	50	25	25	
Выходная мощность, Вт 12)	12	0,3; 1; 8	15—25	40—50	0,13
Чувствительность приемника, мкВ 13)	5	1,5	0,8—1	0,8	
Напряжение питания, В: постоянного тока 14)	26, 100, 200	24	127/220	127/220	9,4
переменного тока	26,110, 127/220	127/220			
15) Потребляемая мощность, Вт	630 (1650)	80 ВА	300	300	1
Габариты, мм: стойки приемо-передатчика 16)	452××305××200	283×260×70	670×30—210	450×190×460 280×215×65	68×30×130
пульта управления					

[Key on following page]

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Key:

1. Technical characteristics
2. Type of radio set
3. "Grafit"
4. "Seyner"
5. "Reyd"
6. "Port-3"
7. "Priboy-UM"
8. Frequency band, MHz
9. ("Port-3D")
10. Number of communications channels
11. Frequency difference between channels, kHz
12. Output power, W
13. Sensitivity of receiver, μV
14. Supply voltage, V: d.c., a.c.
15. Power requirement, W
16. Overall dimensions, mm: racks of radio receiver, of control console

The American ITT "Marine" firm (Scandinavian division) is manufacturing marine radio transmitters, radio receivers and radio sets with remote control consoles. The type ST-1610 main transmitter had a power of 1500 W in the HF band and 800 W in the MF band. For the purpose of ensuring reliability, three electrically independent drivers are employed. The type TP-350V single-band radio telephone set enables duplex communications. Frequency stability is $\pm$ 10 Hz. It has a printing mode. Optimal antenna coupling is established automatically. The single-band type 224A marine radio set is characterized by the fact that in it is provided a unit for storing 20 cards, in which the tuning of 20 communications channels is preprogrammed and in addition provision is made for the storage of 60 cards, whereby the interval between channels equals 100 Hz.

The "Linkompeks" Improved-Reliability Marine Radio Telephone Communications Line

Single-band radio communications systems have made it possible to improve the stability of marine radio communications with the shore and between vessels. However, in single-band radio communications channels, when operating at great distances, a considerable increase in the power of radio transmitters is required.

In recent times in different countries (the USSR, England, Japan and the FRG), more effective models of HF radio telephone sets have been developed, which employ radio speech companders. These companders have MKKR-regulated parameters in conformity with the "Linkompeks" system (a joint compressor and expander), and are designed for marine radio telephone communications lines [7, 47]. The purpose of all operations which are performed in "Linkompeks" units is to compress the dynamic range of the telephone signal transmitted through an HF radio channel, for the purpose of increasing the mean load of the transmitter and obtaining from it considerably greater mean power with higher efficiency. Increasing the mean power considerably improves the noise rejection of communications, since the effective noise in a radio channel is most noticeable in pauses between words or in calm conversation.

A radio compander of the "Linkompeks" type is a highly improved piece of equipment having a number of advantages for HF communications with vessels. Its employment is equivalent to a 10-fold increase in the power of the transmitter [7].

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Tests of the "Linkompeks" system on the London to New Delhi route have demonstrated that the employment of a radio compander makes it possible to increase average daytime commercial communications sessions from 5.2 to 6.2 h, i.e., by 19 percent. The quality of communications is also considerably improved. Of all radio telephone conversations over four weeks, 70 percent were deemed excellent and good, while without a radio compander this type of quality was observed only in 58 percent of conversations. This domestic radio compander has a 300 to 3400 Hz band and in the supersonic frequency band (300 to 3400 Hz) can accommodate a telegraph channel with a transmission rate of up to 200 bauds.

Marine satellite communications system equipment (SSS equipment) enables steady communications between the shore and moving objects located in any area of the global ocean. Via this system communications between vessels is also carried out, and the terminal equipment enables telegraph, telephone and printing communications.

The English Skynet satellite system is designed for equipping vessels of Great Britain's navy--from frigates to aircraft carriers. The "Scot-I" and "Scot-II" type SSS terminal equipment is installed also on large vessels. This satellite system is employed also in other NATO countries.

The "Scot-I" ship variant of the SSS set has two directional parabolic antennas 1.04 m in diameter, enclosed in a protective screen. These antennas are installed on the sides of the ship on stabilized platforms with a gyro system, enabling stabilization with an angle of inclination of five degrees and 20° rolling. A scanning unit keeps the antenna in the direction of the satellite. The antenna is designed for the 1200 MHz band and covers the frequency band from 7.250 to 8.425 GHz. The transmitter, receiver and unit for scanning and tracking the satellite, as well as the set's electronic servo equipment, are placed in an unattended cabin. This cabin, attached to a frame, is installed on the upper deck of a ship or vessel. The cabin's equipment is connected to the antenna by waveguide feeders with a maximum length of 15 m.

A remote control rack is installed in the radio room for the purpose of controlling channel-forming equipment and the antenna. It makes it possible to switch on the transmitter and receiver, to monitor the operation of the radio line "by itself," to select the antenna for communications, and to switch terminal equipment.

The power of the radio transmitter is 1 kW. The set is powered from a 400 V three-phase current or 115 V single-phase current line with a frequency of 50 or 60 Hz. The transmitter is air-cooled and the hermetically sealed container is cooled with sea water. The dimensions of the container are 2.44 X X 1.83 X 2.74 m.

The American "Marisat" satellite communications system is designed for enabling two-way communications between vessels and between vessels and the shore. This system has telephone and telegraph channels, with the ability to connect via

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coastal points to the international telephone and telegraph communications system. The "Marisat" system must enable vessels to communicate directly with the coast and thus meet the requirements of the international "Inmorsat" system.

The "Marisat" marine communications equipment has a directional antenna which is stabilized from rolling by $\pm$ 25° and $\pm$ 7,5° with respect to angle of inclination. For this purpose, long-life static sensors are employed. Stabilization in terms of azimuth is accomplished by means of the ship's gyro compass. After the initial search for the satellite, the position of the antenna is automatically controlled by an electronic tracking circuit. The antenna is protected with a fiberglass fairing. It is installed high on the vessel for the purpose of creating the condition of a clear "field of visibility" for the satellite. The control console for the channel-forming equipment and antenna-feeder system makes up the greater percentage of the system's electronic equipment and is placed in the ship's radio room.

Through the "Marisat" system only printed information addressed to the vessel arrives. The reception of information is totally automated and is carried out without an operator. Information can be addressed to individual vessels or to a group of vessels in a specific area of the ocean. Upon interrogation from a vessel a communications channel is automatically created for 5 s. Then the number of the addressee is dialed from the ship and communication is carried out with any addressee in the communications system. The quality of telephone communications and the fidelity of the transmission of digital information are not worse than in ground communications systems. According to American data it is estimated that, with the expensive sea voyages of today and in long-range commercial fishing, communications via satellite communications systems will make it possible to save annually one or two sailing days for vessels. This will bring a greater gain than the cost of a marine satellite communications complex.

In the U.S. Navy the "Fleetsatcom" [39] satellite communications system is being created, designed for the transmission of information at sea, as well as for the exchange of messages between ships, aircraft and submarines within the range of shortwave radio communications. It is thought that this system will make it possible to improve severalfold the reliability of radio communications with ships.

Hydroacoustic communications facilities have at the present time become of great importance for communications between surface vessels and submerged submarines and between vessels and deepwater equipment and divers (cf. chaps 3 and 6).

The effectiveness of the operation of marine radio communications facilities and complexes depends to a great extent on the proper choice of the structure and types of marine antennas and on their distribution and utilization. For radio communications in the MF band, on vessels are used L- and T-shaped antennas and mast antennas, and in the HF band, antennas designed in the form

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of slanting rays of one or more conductors, and four-, six- and 10-meter whip antennas (four- and six-meter whip antennas are used only as receiving antennas). In the microwave band three main types of antennas are used: directional and non-directional semiconductor dipoles and discone antennas. Several types of marine antennas are shown in fig 5.6 [10]. Marine antennas must withstand the pressure of a wind at a speed of 60 m/s, impact, jarring and vibration.

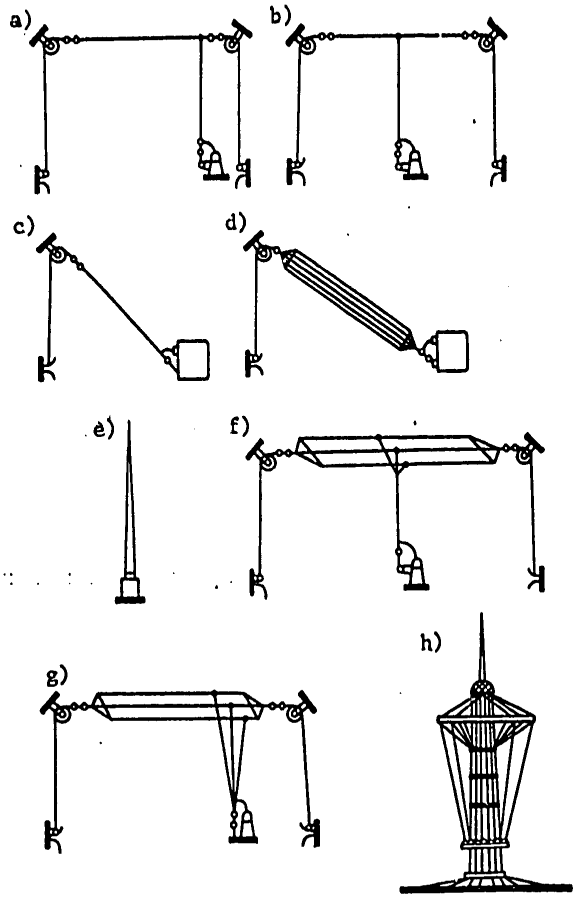

Figure 5.6. Several Types of Marine Communications Antennas: a--L-shaped beam antenna; b--T-shaped beam; c--"slant beam" type; d--cylindrical slant; e--whip; f--T-shaped multi-wire; g--T-shaped multi-wire with multi-wire fan-type down lead; h--mast antenna

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For the purpose of producing a gain in power and extending the range of HF radio communications on vessels and ships, the employment of directional antennas and signal-selective antennas is promising. New type AMS-17 (mast antenna), ShPA-MV (broadband), AS-8M (transmitting) and AS-6M (receiving) antennas are being installed on vessels. An important role is played also by the matching of antennas with the feeder.

For the purpose of reducing the number of receiving antennas on vessels and ships, equipment is installed for accomplishing reception with several receivers from a single antenna. In the U.S. Navy, in the creation of control ships of the "Northampton" type and of communications and radio relay ships of the "Annapolis" type, which have as many as 100 communications antennas, special attention was paid to the optimal distribution of antennas. First, with models of ships on a scale of 1/48 and 1/96, studies were made of antenna parameters (directivity diagrams), input impedances, e.m.f. induced from transmitting antennas into receiving antennas, etc. Then, by rearranging antennas and sampling different types, conditions were created whereby the e.m.f. induced in receiving antennas was reduced by 30 to 40 dB, as compared with the variant in which these antennas are placed near the transmitting antennas.

5.3. Equipment Principles; Distribution and Control of Communications Facilities for Vessels and Ships

In determining the structure of communications equipment and its distribution on vessels and ships, it is necessary to take into account the following fundamentally important conditions.

1) The structure of communications facilities in terms of quantity and quality of communications channels, as well as of types of communications, must ensure the best fulfillment of the objectives facing a vessel or ship.

2) Communications facilities are grouped by communications posts, rooms and centers. Radio receivers and terminal equipment are placed in the ship's radio room, which is located near the wheelhouse, and at the communications command post, which is located alongside the ship's command station. This makes possible rapid delivery of information received to the vessel's captain and the commanding officer of a ship and an opportunity for them to make calls.

A great number of radio receivers can be placed at individual posts (radio reception centers). Similarly, radio transmitters can be located in radio rooms or at individual posts (radio transmitting centers).

3) The transmitters and radio transmitting centers of vessels and ships are located at a distance from receivers and radio reception centers. Antennas are located in the area of the location of radio transmitters, receivers and individual radio centers. Here one strives for a minimum length for feeders (15 m and shorter). The architecture of vessels and ships must take into account requirements for the separation of transmitting and receiving antennas,

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as well as for the placement of microwave communications antennas at great heights. Circular coverage must be made possible for microwave antennas.

4) The equipment in the radio rooms of vessels and at the communications posts of ships must be so arranged that maximum efficiency is made possible in the utilization of communications facilities and the best working conditions are created for personnel.

5) Radio receivers must be ensured protection from the influence of all kinds of interference.

6) The communications complex and facilities of a vessel or ship must be automated to a sufficient degree, and the remote control of radio transmitters must be possible at distances of up to 150 m [51]. The control consoles for communications complexes must be placed in the operator's section of the radio room of a vessel and at the communications command post of a ship.

Marine radio communications facilities, including auxiliary equipment for sets, also, including control console equipment (power and charging panels, commutation equipment, and the like), are placed in radio rooms and in the wheelhouse.

In the radio rooms of vessels of the first group, in keeping with the rules for conventional equipment [58], are installed the "Dyuna" control console for the vessel's radio communications facilities complex, "Musson" and "Brig" radio transmitters, "Shtorm-III" and "Shtorm-I" radio receivers, the receiving antenna commutator, the KK2X2-1 transmitting antenna commutator, the remote control console for the transmitting antenna commutator, the telephone-telegraph commutator, a "Tembr-2s" tape recorder, a Morse code sender, an EKM-ZA electronic switch, a typewriter, a telephone set, a telegraph key, a marine clock, two STA-M67 (T-63, RTA-7B) printers, and an FAK-P facsimile telegraph unit. The STA-M67 and FAK-P equipment is as a rule installed in individual compartments in radio rooms, which hold equipment for improving the fidelity of printer channels, as well as the remote control console for the "Brig" radio transmitter, and the "Sibir'" or "Shtorm-III" radio receiver with their power supplies.

In the wheelhouse are installed a "Prizyv" radio set, an automatic alert, distress and coordinate signal transmitter, a storage battery and the "Prichal" radio set.

The automatic alert signal transmitter with equipment for transmitting the vessel's coordinates is placed in the navigator's area of the wheelhouse, and the possibility of remote triggering of the standby (emergency) transmitter must be ensured.

The radio room is divided into equipment and operator areas. In the equipment area are installed transmitters, the transmitting antenna commutator, and the "Sirena" standby (emergency) communications complex, which includes a radio transmitter with a rectifier and an automatic alert, distress and

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coordinate signal transmitter and a storage battery. In the operator's area are located the remaining radio equipment and a "Reyd" microwave radio set for traffic control communications, an APM-3 automatic radio telegraph signal receiver, and an "Avral-I" automatic radio telephone alert signal receiver, as well as an EDR electronic transmitter, enabling the radio relaying of signals in the ship to shore direction and vice-versa.

Controls and monitoring devices for the equipment of main, standby (emergency) and operating communications facilities must be located near the work place of the main watch. If there are two work places (the second for the operating communications line), then communications facilities are controlled separately. In this case, at the main work place provision is made for the possibility of switch operation of the operating transmitters.

The automatic radio telegraph alert signal receiver is installed so that its operation can be easily monitored hour by hour. The automatic radio telegraph alert and distress signal transmitter is placed near the standby (emergency) transmitter.

A sample diagram (variant) of the location of radio communications facilities in the radio rooms of vessels of the first group is given in fig 5.8.

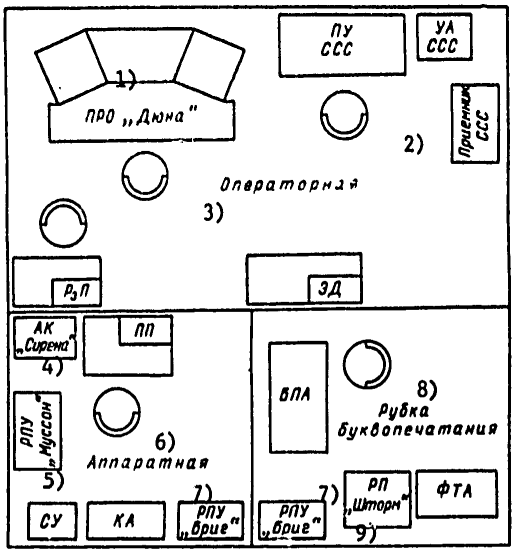

Figure 5.8. Location of Radio Equipment on MMF and MRKh Vessels (Variant): "Dyuna" PRO--radio operator's console; PU SSS--satellite communications system control console;
[Caption continuation and key on following page]

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UA--SSS antenna control unit; R_2P--standby receiver; AK--emergency complex; PP--transceiver; SU--matching unit; KA--antenna commutator; BPA--printer; ED--electronic transmitter; FTA--facsimile telegraph unit

Key:

1. "Dyuna" PRO
2. SSS receiver
3. Operator's area
4. "Sirena" AK
5. "Musson" RPU [radio transmitter]
6. Equipment area
7. "Brig" RPU
8. Printer room
9. "Shtorm" RP [radio receiver]

The main command microphone post with the amplifiers for the command radio relay equipment, as well as the radio broadcasting receivers belonging to it, grammophone record players and sound recording equipment, are placed in a special area--the command relaying center.

On large ships, radio communications equipment is placed chiefly at receiving and transmitting centers. For example, the location of communications facilities in the radio receiving and transmitting centers of the U.S. destroyer "F. Sherman" is shown in fig 5.9.

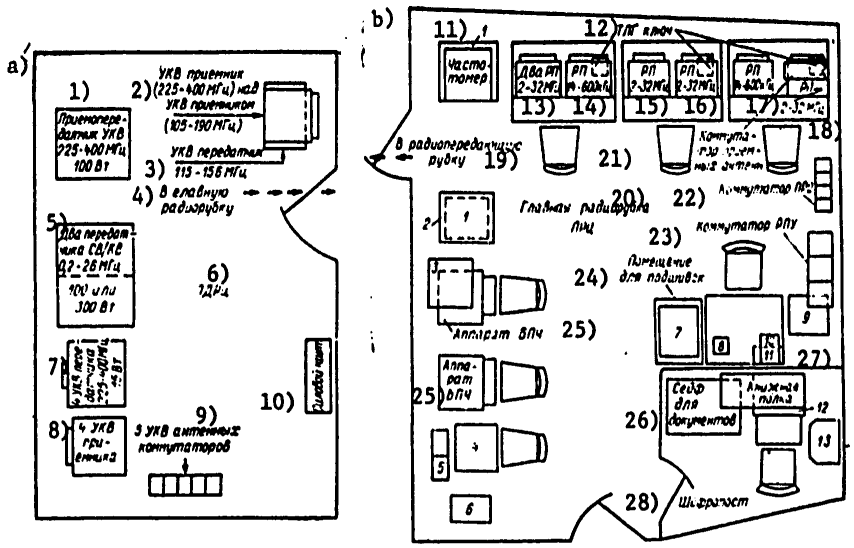

Figure 5.9. Location of Radio Equipment on the U.S. Navy Destroyer "F. Sherman:" a--at radio transmitting center; b--at radio receiving center; RP--radio receiver; TLG--telegraph key;

[Caption continuation and key on following page]

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BPCh--printer; 1--radio broadcast receiver; 2--frequency modulus converter-comparator; 3--tone modulator-converter; 4--printer re-puncher; 5--printer distributing board; 6--printer distributing and transmitting unit; 7--unit for monitoring radio frequencies; 8--telegraph key; 9--ZIP [accessories kit] for unit for monitoring radio frequencies; 10--radiotelephone unit; 11--low-frequency amplifier; 12--coder; 13--classifier

Key:

1. Microwave transceiver, 225 to 400 MHz, 100 W
2. Microwave receiver (225 to 400 MHz) over microwave receiver (105 to 190 MHz)
3. Microwave transmitter, 115 to 156 MHz
4. To main radio room
5. Two MF/HF transmitters, 0.2 to 26 MHz, 100 or 300 W
6. PDRTs [radio transmission center]
7. Four microwave transmitters, 225 to 400 MHz, 15 W
8. Four microwave receivers
9. Five microwave antenna commutators
10. Power board
11. Freq-meter
12. TLG key
13. Two RP's, 2 to 32 MHz
14. RP, 14 to 600 kHz
15. RP, 2 to 32 MHz
16. RP, 2 to 32 MHz
17. RP, 14 to 600 kHz
18. RP, 2 to 32 MHz
19. To radio receiving room
20. Main radio room of PRTs [radio transmitting center]
21. Receiving antenna commutator
22. PRO commutator
23. RPU commutator
24. File area
25. BPCh
26. Safe for documents
27. Bookshelf

In solving problems relating to equipping vessels and ships with communications facilities and distributing them, it is necessary to take into account the principles of designing a system for protecting radio reception from interference, which must ensure the suppression of interference from marine electrical equipment and radar sets, as well as the combined operation of radio communications facilities.

The system for protecting radio reception from interference from electrical equipment and RLS's [radar sets] is based on the combined utilization of shielding and filtering.

On the basis of the structure of the radio and electrical equipment installed on the vessel or ship, it is necessary to determine areas which require shielding. In shielded areas must be placed equipment subject to the influence of interference and electrical equipment which radiates powerful fields. The radio rooms of vessels and the radio communications posts of ships are shielded, as well as areas where radio relay equipment is installed.

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The shielding of antenna circuits is one of the most important elements in the protection of radio reception. The stationary laying of antenna circuits for marine HF radio transmitters is done with RKS brand cable, and of commutation elements, with flexible RKG brand cable. For conduits for high-frequency vibrations in the MF band, high-frequency channels are used, in which the sheath is the shield. The separate laying of antenna circuits is called for on special USSR Academy of Sciences research vessels having highly sensitive radioelectronic communications equipment and measuring complexes.

In keeping with the rules for conventional equipment on vessels, it is required that the radio operator on duty, without getting up from his work place, perform the following operations: turn on and off the channel forming equipment for radio communications; make use of controls for receivers and the standby (emergency) transmitter, and attend to aural reception and the recording of the content of messages; transmit by key and telephone; observe readings of measuring instruments and the position of channel forming equipment controls; follow the readings of the clock and signals from the light signal system of the auxiliary radio direction finder designed for direction finding of the broadcasts of vessels in distress; and make use of the intercommunication system. It is desirable that the operator be able to control the tuning of all transmitters from his work place.

These requirements are being satisfied at the present time by the "Dyuna" remote control console, developed for medium and large tonnage vessels of the maritime and commercial fleets. The "Dyuna" makes it possible to concentrate at the work place of the communications operator all control of radio telegraph and radio telephone communications facilities. Installed in it are the following: a remote control console for the "Musson," "Brig" and "Korvet" radio transmitters, a "Shtorm-III" radio receiver, a remote control console (PDU) for the "Shtil'" radio receiver, the receiving antenna commutator, the PDU for the transmitting antenna commutator, the telephone and telegraph commutator, a "Tembr-2s" tape recorder, a PDU for the "Reyd" radio set, a Morse code sender, an EKM electronic switch, a typewriter, a telephone set, a telegraph key, a marine clock and a "Shtorm-I" radio receiver for aural monitoring. The "Dyuna" console makes possible the remote control of these radio transmitters and receivers, the commutation of antennas by means of the PDU, and the interformation of circuits between the equipment connected to and built into the console.

The American ITT firm (Scandinavian division) is making for ships and vessels of the first group a complex of communications facilities united by a control console which accommodates the following: a control console for the radio transmitter, an antenna commutator, a standby transmitter, the main receiver, the standby receiver, a radio transmitter frequency synthesizer, a microwave radio set, an automatic alert signal receiver, a loudspeaker communications console, a channel distributing and monitoring console, and an automatic switch.

The automation of the control of a ship's communications facilities calls also for the automation of the delivery of information to the commanding officer and navigator and to other control posts on the vessel, and especially for

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the distribution and delivery of information on large passenger and fish processing vessels, expeditionary flagships and headquarters vessels, the vessels of MRKh flotillas and on ships. Automation also calls for the connection of user stations on a vessel or ship to the channels of automated ASU [automated control system] communications complexes.

Computers are used for the purpose of automating communications processes in ship communications complexes in the U.S. and British navies.

5.4. Electromagnetic Compatibility of Radio Communications Facilities and Other Radioelectronic Facilities; Protection of Personnel

In distributing radio equipment on a vessel or ship it is necessary to take into account the effect on radio receiving equipment and personnel of electromagnetic fields created by different equipment of the vessel or ship, and protection from this effect.

The electromagnetic fields created by radio transmitters, radar sets and other electrical and electronic equipment are of different structure and strength. The noise originating in any piece of equipment can be propagated not only by means of the direct radiation of electromagnetic fields, but also through power cables and cables between instruments as the result of induction from some electrical circuits to others. The magnitude of the noise field depends on the length of the wave radiated, λ , and the distance, R , from the source. The effective values of the noise making up the field are discussed in detail in [13]. Paths for the penetration of radio noise into a radio room and a radio receiver are illustrated graphically in fig 5.11 [13].

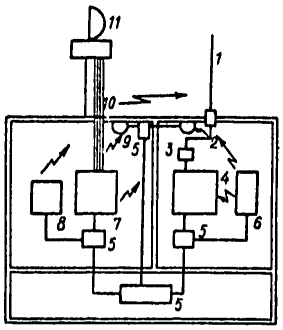

Figure 5.11. Diagram of Paths of Influence of Radio Noise on a Marine Radio Receiver: 1--receiving antenna; 2--receiving antenna feeder; 3--antenna switch; 4--radio receiver; 5--distributing panels and boxes; 6--printer (or other noise creating equipment inside the radio room); 7--RLS [radar set]; 8--navigator's equipment; 9--lamps; 10--RLS cables and waveguide leading to antenna; 11--RLS antenna with turning motor and other equipment

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According to MKKR recommendations, the signal-to-noise ratio at the receiver's input, $k = u_s/u_n$, sufficient for distortion-free reception must not exceed the norms indicated in Appendix 1. Practice has demonstrated that if no measures are taken to suppress the radio noise arising from marine equipment, then it can exceed the values indicated in the appendix by a factor of 10 to 100 and more [13]. Consequently, for the ensurance of long-range radio communications an effective shielding system is required. According to the rules of the USSR Registry, it is required that the increment in noise at the input of radio receivers resulting from the effect of radio noise created by marine equipment does not exceed 20 percent, i.e., in order for the sensitivity of radio receivers on vessels to be practically completely realized.

In terms of origin, noise is divided into natural and artificial. Natural noise includes atmospheric noise, which is perceived in a receiver as continuous rustling noise. The mean value of the field strength of atmospheric noise in winter reaches 0.2 to 1.2 μV/m at night, and is reduced 35- to 80-fold in the daytime [13].

Artificial noise from marine electrical machines not having a metal housing reaches 3000 to 5000 μV at a distance of 1 m. The noise from them is strongest at low frequencies and is reduced with an increase in frequency. RLS's are radiators of powerful electromagnetic vibrations, and at the same time strong noise is created from the stray radiation of radar set modulators and pulsed units. In the absence of special noise suppressing filters, noise levels from an RLS can reach 10,000 to 100,000 μV at frequencies below 5 MHz. The same noise levels are observed at the output terminals of magnetic amplifiers. Power rectifiers (up to 200 A) at a frequency of 50 Hz create radio noise voltage of up to 105 μV. Fluorescent lamps with protective capacitors create noise up to 200 μV at frequencies of 0.15 to 5 MHz, and to 50 μV at frequencies of 5.0 to 150 MHz. In the operation of marine and ship radio transmitters, radio reception noise can originate in the rigging of upperdeck equipment, in transceiving antenna circuits and directly in the radio transmitting equipment.

The system for shielding radio reception from noise, implemented on vessels, accomplishes the following [13]: the suppression of noise voltage in its sources; ensurance of definite noise immunity for radio receivers; fulfillment of the necessary requirements relating to the distribution of radio receiving equipment and noise sources on vessels; execution of the shielding of noise-carrying and noise-sensitive cables; provision for the additional filtering of individual cables and the performance of measures for increasing radio noise attenuation along the paths of its propagation through marine cable routes; provision for shielding measures in marine upperdeck equipment.

For the purpose of ensuring the electromagnetic compatibility of the operation of radio communications facilities and other RES's [radioelectronic facilities] on a vessel, of great importance is the intelligent distribution of receiving and transmitting antennas. When they are distributed over a limited space, voltages can be induced in receiving antennas whose values in individual instances reach 100 V [13]. And the number of antennas on ships is great now

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and has a tendency to grow. For example, on a modern American aircraft carrier having 56 transmitters and 84 receivers [104], it has reached 100 antennas.

The high values of high-frequency voltage arriving at the input of radio receivers can result in its blanking, the origin of noise of the "hiss" type in elements of input circuits, and, finally, in the radio receiver's going out of order. When receiving and transmitting antennas are placed in mutually perpendicular planes, induced voltages are reduced considerably. For a 1 kW radio transmitter, the distance between receiving and transmitting antennas must be no less than 20 m. For high-power transmitters, the distance between receiving and transmitting antennas must be increased.

When two or more microwave radio sets are installed on vessels or ships, the conditions must be created for their joint operation. For the attenuation of reciprocal noise in the microwave band, the distance between the closest microwave antennas must be not less than 5 to 6 m [13]. For the attenuation of the influence of RLS's, microwave antennas must not be placed in a zone of their primary radiation. It is possible to reduce to permissible levels the effect of noise from RLS rotating motors and other mechanical connections in the structure of RLS antennas by placing microwave communications antennas at a distance of not less than 5 m from the RLS antenna.

For protection from noise propagated through power supply circuits, special filters are installed in radio receivers, the internal assembly is shielded, and a number of other measures are carried out. Required in radio receivers are a reliably shielded chassis and the shielding of individual assembly units from the effect of external radio noise fields. The shielding effectiveness of marine radio receivers must not be less than 60 dB, and the effectiveness of the filtering of power supply circuits, 80 dB. Used as the maximum permissible noise voltage in the power supply circuit of a receiver is the value at which the total voltage of the interference and noise at the receiver's output exceeds by a factor of 1.2 the level of the receiver's intrinsic noise.

In designing marine radio receivers, appropriate measures must be provided for shielding input circuits from induced voltage from the radio transmitters of the vessel itself. At the present time the input circuits of radio receivers have special devices (chiefly spark gap tubes) which shunt the receiver's input with voltages on the order of 80 V [13].

For marine radio receivers the following voltages for the oscillator in the receiver's antenna input channel must be ensured [13]:

Band, MHz	U, μV
0.01 to 1	10
1 to 10	20
10 to 30	40
Over 100	100

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All radio transmitting equipment made by plants, intended for installation on vessels and ships, in the bench test period must pass special tests to determine the level of noise of the "hiss" type which it creates, which must not be greater than 20 percent of the receiver's intrinsic noise level. The frequency band affected by noise of the "hiss" type must not be greater than $\pm$ 10 to 15 percent of the radio transmitter's fundamental tuning frequency with high-frequency voltage of 3 and 30 V in the receiver's input.

Testing of the effectiveness of the shielding of a radio receiver from noise created by electrical equipment and RLS's is performed by monitoring and measuring noise levels at the output of marine radio receivers, while alternately switching on the RLS's and electrical gear being checked. These tests are performed in the roadstead at a distance of not less than two miles from coastal noise sources. Noise created by engines and d.c. generators is picked up as continuous crackling with a high repetition rate for individual pulses, and in the case of high-r.p.m. motors, in addition to crackling a tone sound is also heard. Sound signaling devices (bells, loud-sounding bells, etc.) create noise of a crackling nature, but with a lower pulse repetition rate.

Marine RLS's can create noise of two kinds: 1) from the antenna rotation motor (nature of detection described above) and 2) from the transmitter's modulator--as a continuous tone at the RLS's modulation frequency.

Noise created by the ignition system of internal combustion engines is in the form of alternating clicks whose repetition rate corresponds to the number of contact breaker contact openings in the engine's ignition system.

After determination of the noise source, its paths of propagation are determined, and then the method of suppression. Noise can penetrate a radio receiver along three paths (cf. fig 5.11): through the power circuit, directly via the active section of the antenna, and as the result of stray induction in the antenna-feeder circuit.

Most often the stray radiation of noise acts directly on the active sections of receiving antennas. The reason for the origin of noise can also be a break in the grounding or shielding of cables, and in some instances individual electrical equipment located in the immediate vicinity of radio communications receiving antennas. In this case, by switching the radio receiver to different antennas a determination is made of the antenna with the highest noise level, and the noise source is found in this manner.

The effectiveness of shielding from radio noise propagated through power circuits is tested with regular marine radio receivers with the antenna cut off. More complex is the problem of evaluating protection from radio noise entering the receiver's input through antennas, since in this case measurements are made with the radio receiver connected to the antenna, i.e., under conditions of the influence on it of an added atmospheric noise level. This method is described in detail in [13].

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In certain cases, for a more detailed study of the effectiveness of shielding performed on a vessel or ship, additional tests can be made for determining the extent of the attenuation of radio noise propagated through marine cable routes, as well as the transfer coefficients for noise from marine electrical lines to radio communications receiving antennas. These tests are made on prototype tankers and vessels with non-metallic hulls, as well as on vessels and ships whose shielding system has higher requirements.

Noise attenuation is expressed in decibels and is determined by the equation:

$$K_{\text{п}} = 20 \lg U_1/U_2, \tag{5.1}$$

where U_1 is the voltage created by the generator and U_2 is the voltage measured on the radio room board.

For each vessel the required points for connecting the IKP [transfer coefficient meter] generator are determined on the basis of its specific level of outfitting with electrical equipment and radio equipment. Measurements of coefficients of transfer to receiving antennas are performed in a similar manner, with the noise meter connected alternately to all receiving antennas.

A schematic diagram for measuring the attenuation of radio noise and transfer coefficients, as well as of points for connecting a transfer coefficient meter (IKP), is given in fig 5.12 [13].

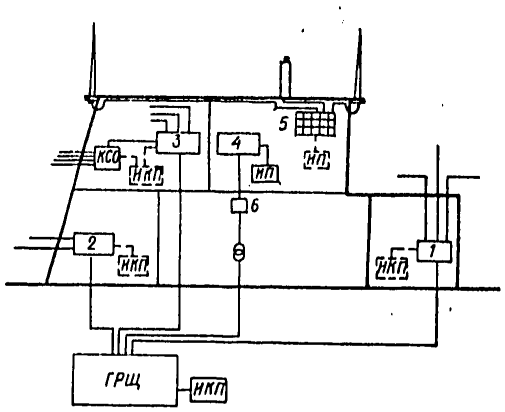

Figure 5.12. Diagram for Measuring Transfer Coefficient and Attenuation of Radio Noise: IP--noise meter; IKP--transfer coefficient meter; GRShch--main distributing board; KSO--signal lamp commutator; 1--marine RLS power circuit board; 2--outside lighting board; 3--navigator's room board; 4--radio room board; 5--receiving antenna commutator; 6--noise suppression filter

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A determination of the feasibility of the joint operation of marine radio communications facilities must be made while the vessel is moving.

The joint operation of marine radio communications facilities is evaluated by the size of the affected band of the receiver when internal radio transmitters are operating. The segment of a radio receiver's frequency band affected by noise at frequencies below 1 MHz can reach three to five percent of the radio transmitter's carrier frequency. This band reaches a maximum at frequencies of 8 to 12 MHz, and then shrinks somewhat at higher frequencies. With an increase in the vessel's speed, as well as in circulation, the vibration of the hull increases and there is an increase in the level of noise originating in marine upperdeck equipment. When the vessel is at anchor, with maximum separation of antennas, the band affected by noise should be practically nonexistent, or should not exceed the values of the spurious frequency radiation band for the marine transmitter in question.

The protection of personnel requires a broader approach, since in addition to radio waves a number of other factors influence the body of a radio operator. Exerting a direct influence on the state of health and the capacity for work of a human being are superhigh-frequency radiation, acoustic noise, unfavorable meteorological conditions, insufficient lighting of work places and disruptions of heat conditions.

For a rough determination of the intensity of exposure in the remote zone of a radio transmitter or radar set is used the equation for the power flux density, P, at distance R with radiated power of P_{sr} [32]:

For non-directional antennas:

$$\Pi = \frac{P_{cp}}{4\pi R^2}, \tag{5.2}$$

For directional antennas:

$$\Pi = \frac{P_{cp} G}{4\pi R^2} \cdot 10^2 F(\theta_g, \theta_r), \tag{5.3}$$

where G is the antenna's gain; $F(\theta_v, \theta_g)$ is the expression for the directivity diagram in general form, when at the center of the beam $F(\theta_v, \theta_g) = 1$.

In modern RLS's the power in a pulse reaches a few megawatts, and the mean power (P_{sr}) up to 1 MW. Knowing P_{sr} (in watts) and the antenna's gain, G, it is possible to determine the value of the power flux density, P ($\mu W/cm^2$), at R (cm).

With the effect of electromagnetic energy in the microwave band on a living organism, part of the energy is absorbed by the tissues, and part is reflected.

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In the UHF band the reflected portion equals about 50 percent. The depth of penetration of superhigh frequencies increases with an increase in wavelength. The eyes are especially vulnerable to the effect of microwaves. With high microwave radiation it is obligatory to employ protective eyeglasses and clothing.

The level of mechanical noise created by communications facilities and other equipment in the radio room during the measurement period must not exceed 60 dB at a distance of 1 m.

Unfavorable working conditions for personnel arise as the result of an increase in temperature and positive radiation from heated surfaces, when the temperature reaches 35 to 40°C and higher.

In the radio room it is necessary to provide ventilation and heat, to maintain the temperature within the range of +18 to 23°C, and the relative humidity within the range of 65 $\pm$ 15 percent.

The radio room must have sufficient natural and artificial lighting. With emergency lighting it is necessary to provide an illumination intensity of not less than 50 lx at the clock dial and face panels and at the work place.

5.5. Prospects for the Development of Facilities for Communications with Vessels and Ships

The prospects for the development of marine and ship communications facilities are governed by trends in the solution of key problems relating to communications at sea. First among these must be named improvement in reliability in carrying out communications at great distances, and reduction in the level of reciprocal noise, especially on ships. For solving this problem it is necessary to increase the power of the radio transmitters of vessels and ships and the sensitivity of their radio receivers, and to improve antennas. As noted in American publications, the peak power of transmitters on ships exceeds 1 MW, which creates in the inputs of radio receivers interfering voltages of 160 to 250 dB, with respect to the signal arriving from the receiving antenna. The separation of antennas on a ship reduces the noise level at the input of radio receivers by no greater than 10 to 40 dB.

For the purpose of combating reciprocal noise on a ship, in the USA the following key guiding principles are used:

1. The radiation of each kind of ship's radio facility should occupy a minimal segment of the electromagnetic spectrum for the minimum possible time.

2. The output circuits of transmitters and the preselectors of receivers should load antennas only within the range of a narrow frequency segment necessary for normal operation of the equipment. This will make it possible to accomplish the simultaneous employment of antennas by several pieces of equipment and will reduce their number on the ship.

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3. Each broadcast over great distances should begin with a definite control signal with reference to which the threshold for triggering the ARU [automatic gain control] is set in the receiver and compensation for the Doppler shift is introduced in the demodulator.

4. Each ship should have at its disposal current information on conditions for the propagation of radio waves along the radio route of interest, for the selection of optimal communications frequencies.

5. The creation of reliable plug connections.

Besides, in the USA other solutions have been discussed, in particular, automatic changing of the receiving channel's passband as a function of the level of interfering signals. In the creation of a ship communications system, the Americans have developed a system of circular and directional radiation with electrical control of the beam within the range from ultralow frequencies to frequencies of a few thousand MHz. This system should automatically sustain tuning of the receiver to a signal with a level of a few microvolts under conditions of noise of a very high level from transmitters of its own and neighboring ships.

In the future it is suggested that a changeover be made to combined systems on vessels and ships which unite communications systems and radio navigational and other electronic equipment. The design of such systems will call for the simultaneous utilization of a single antenna by several pieces of equipment. Control of the elements of this combined ship system must be accomplished with a computer, which automatically selects the optimal operating conditions for each element of the complex under different tactical conditions.

Improvement of the reliability of communications facilities must be achieved on the basis of introducing microelectronic circuitry. The weight and dimensions of equipment are thereby reduced dramatically. For example, according to American data, the dimensions of ship equipment can be reduced five- to 100-fold, the weight two- to 50-fold, and the power requirement two- to 20-fold. The mean cycle between failure will be counted in years.

The convenience of equipment repairs should be made possible by employing replaceable modules, by the parallel operation of identical modules, and by the employment of self-monitoring and self-repairing circuits. It is necessary to take into account the need to replace individual modules in the event of their obsolescence. This will make it possible to maintain communications facilities for a long time at a fairly high level and to perform modernization operations on vessels and ships without large outlays of money.

Another problem governing the trend in the development of marine facilities is the improvement of carrying capacity. The chief thing along this line is to increase the percentage in the exchange of information with vessels of HF printing, facsimile telegraph and telecoding communications channels and of single-band telephone communications channels. HF radio communications

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will obviously for a long time yet bear the major burden of marine information traffic, but in the future the introduction of satellite communications facilities will make it possible to relieve HF radio communications and, the main point, increase the carrying capacity of marine communications systems, as well as to reduce considerably the time for the travel of messages. Satellite communications, in addition, will improve considerably the reliability, and, especially, the fidelity of communications over great distances.

One of the most important trends in the development of communications facilities for vessels and ships is the automation of facilities and the system as a whole, which will result in a dramatic reduction in the time required for the travel of information and in the necessity to solve many problems, such as improving the fidelity of communications, linking communications channels with computers, etc.

Mention should be made of the trend in all fleets of large foreign sea powers in the world of creating control ships (headquarters ships) well equipped with communications facilities. When vessels and ships sail in large formations and in the joint fulfillment of objectives in a single area, it has been shown to be necessary to have one ship or vessel equipped with a considerable amount of ideal facilities for carrying out high-quality communications over great distances. This ship provides communications with the shore for the entire group or formation. Control ships and the flagships of a commercial fleet as a rule have better communications facilities than other vessels and ships. But it is not always possible to solve all the problems which arise in ensuring reliable, high-fidelity and rapid communications over great distances, and, even more so, with large flows of information. Therefore, in addition to control ships, abroad have appeared special ships for ensuring reliable communications for a formation over great distances--communications ships. In the U.S. Navy these ships are called radio communications and radio relay ships (cf. fig 5.7). With communications ships it is possible to achieve the most favorable conditions for carrying out communications, by means of separating antennas on large antenna decks, by the most convenient distribution of radio receiving and transmitting centers, and by thorough combining of HF radio communications and tropospheric and satellite communications lines.

Chapter 6. Equipping Submarines and Deepwater Devices with Communications Facilities

6.1. Fundamentals of Requirements for Equipping Submarines and Deepwater Devices with Communications Facilities

A modern submarine is outfitted with complicated radioelectronic complexes whose cost is 40 to 60 percent of the total cost of the submarine [17]. Up until recent times the designing of ships amounted primarily to the development of a hull capable of holding a specific load weight, determined by the makeup of rigs, combat equipment and the personnel operating it.

In the 70's, in the U.S. Navy a changeover has been made to a new systems approach toward problems of ship design, the purpose of which is to unite

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in a single whole tactical, technical and economic problems, to find a correlation between them, and, guided by appropriations, to ensure the necessary level of military effectiveness of a ship as early as in the designing process [95].

In addition to subsystems for weapons, power, navigation, etc., on each submarine there are subsystems for communications, for gathering information from subsystems and for exchanging information. Consideration of each subsystem shows that they are all linked to the communications subsystem. It is the key link connecting the submarine's commanding officer with the higher command, enables the gathering of information from other subsystems and plays a major role in ensuring coordination of the operation of all combat equipment and weapons on the submarine.

In designing this subsystem very great complexity is entailed in satisfying requirements for economy of weight, volume, area and electric power, electromagnetic compatibility (EMS) and the location of antennas. The solution of the last two problems is especially difficult because of the fact that when a submarine is at periscope depth for the solution of problems relating to communications, observation, etc., almost all radioelectronic equipment must operate simultaneously, without interfering with each other, and utilizing an extensive range of frequencies. For this it is necessary to install a great number of antennas, and this is complicated because of the lack of space on a submarine, the close position of antennas for different purposes, and the influence on antennas of metal superstructures and extensible equipment. No less complicated is the problem of the effectiveness of control of the subsystem as a whole and of its elements. These problems are best solved with a computer.

In spite of the diversity of the problems solved by submarines for different purposes, it is possible to base the structure and amount of communications facilities for them on the basis of common requirements. The successful fulfillment of any objective depends to a considerable extent on the presence of timely and complete information on the situation in the military operations theater and on circumstances immediately in the area of the submarine's combat activity. The submarine obtains this information as a rule from coastal command stations through VLF and ULF radio communications channels, in the submerged position, and through HF and microwave channels in the surface position or at periscope depth.

In addition, any submarine must have the ability to transmit information to the shore or to interacting forces, which is possible at periscope depth or in the surface position in the HF or microwave bands.

When a submarine is in the submerged position, communications with other submarines and surface vessels is possible through a hydroacoustic communications channel.

Intraship communications is necessary on a submarine, and, for enabling the transmission of emergency and distress signals, facilities making possible

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the transmission of messages in the submerged position. Regardless of the purpose of deepwater devices and vessels, they have equipment employed for the purpose of transmitting information through a hydroacoustic communications channel.

6.7. Principles for the Equipment and Location and Design Features of Antennas on Submarines

For communications, on foreign submarines frequency bands from dozens of Hz to hundreds of MHz are employed. Required for each band is its own antenna equipment and feeder lines, and they have important differences. The outfitting of a submarine with different electronic equipment results in a drastic increase in mutual interference and the alteration of directivity diagrams, which worsens the quality of their operation. The antennas of the communications facilities of a submarine do not form an independent subsystem, and in solving the problem of the effectiveness of their operation in the presence of other electronic subsystems and their antennas tolerable compromises are often necessary.

In the U.S. Navy the process of planning the location of antenna complexes boils down to the following: A list is made of the ship's electronic equipment and of the antennas needed for it, a preliminary study is made of the structure of the antenna complex for the purpose of determining required and possible compromise solutions, measures are designated for the maximum possible elimination of the mutual influence of different antennas, an initial plan is made for the location of antennas, from which the necessary calculations are made, and a model is built of the ship's antenna complex [84].

Occupying the special attention of designers is the problem of reducing on a submarine the number of antennas by combining their functions and imparting maximum broadbandness to each antenna. Having determined the necessary number and types of antennas, designers proceed to their tentative location and an estimate of e.m.f. In selecting places of installation areas for launching rockets and admitting torpedos and other cargo are excluded. After this, on a special bench a model is made of the ship, the antenna field and the surface of the sea, measurements are made of the key characteristics of antennas, and based on this a plan is prepared for the location of antennas with the necessary explanations.

The following are the key requirements for submarine antennas: minimal losses of energy in an antenna in the conversion of energy, minimal dimensions, and broadbandness, omnidirectionality or the presence of equipment for controlling the characteristics of the directivity diagram; airtightness, streamlining and invariability of the speed, maneuvering and noise characteristics of the submarine.

As reported by foreign publications, these requirements are satisfied in the following manner.

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The first requirement is considered fulfilled primarily by matching the transmission line (coaxial cable) with the load. It is considered that the cable is matched with the load if the traveling wave coefficient equals 0.6 to 0.7. The length of the high-frequency cable connecting communications facilities to the antenna must not exceed 180 to 200 m.

Fulfillment of the second requirement--broadbandness--is hampered by the preestablished dimensions for submarine antennas. Out of design considerations it is advisable to have a single antenna for the entire HF band (from 2 to 30 MHz). From the technical standpoint it would be ideal to have a half-wave vertical antenna for each frequency in this band, which would ensure circular directivity at small angles with low surface losses. In the U.S. Navy a standard antenna 10.7 m long is used, which is a half-wave antenna for a frequency of 7 MHz.

The requirement of omnidirectionality for antennas is explained by the fact that in this case there is no need for the submarine to follow a definite course in the communications period. The majority of submarine antennas have a circular directivity diagram. An exception is ULF and VLF receiving antennas. But the characteristics of these antennas can be controlled.

Since antennas are located outside of the pressure hull, then they must not lower the safety factor. At the present time the depth of submersion of American nuclear submarines has increased to 480 m, and of the experimental "Dolphin" submarine, 670 m [73]. Deepwater equipment is submerged to even greater depths (10,000 to 11,000 km). The requirement for preservation of the working capacity of antennas on series produced submarines is the absence of leakage of water through the seals of cables with a hydrostatic pressure of 40 to 60 kg/cm^2 [5].

The streamlining of antennas is required primarily on account of an attempt to reduce wakes and to eliminate the appearance of acoustic noise from radio communications antennas during travel in the submerged position. For this purpose, the masts of extensible equipment are enclosed in streamlined housings at their upper end.

Antennas for underwater radio reception (VLF and ULF) in foreign fleets are structurally divided into antennas fastened in stationary fashion to the submarine's hull (sometimes on a telescoping mast), towed antennas and released antennas.

From the structural standpoint antennas installed in stationary fashion on the enclosure of the radio room are more convenient than towed antennas. But they are located within the range of the submarine's electromagnetic field. A loop antenna is widely employed for VLF reception and as a radio direction finder antenna. It represents a multi-turn design in which the total length of all the loop's turns is less than $\lambda/4$.

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The effective height of the loop, h_d (m) , equals:

$$h_д = \frac{2\pi nS}{\lambda}, \tag{6.1}$$

where $S = bh$ is the area of the loop, b is the width, h is the height of the loop, and n is the number of series connected turns.

It follows from equation (6.1) that the greater are S and n and the shorter the wavelength, λ , the more effective the loop.

Because of restrictions on the length of a turn in the VLF band, dimension b is always much less than the wavelength. In any case, the effective height of the loop is not too great.

When the plane of the loop makes an angle of α with the direction of arrival of the wave, the effective height is calculated by the equation:

$$h_д = \frac{2\pi nS}{\lambda}\cos\alpha. \tag{6.2}$$

In a polar system of coordinates equation (6.2) has the form of two circles (a figure eight). For the purpose of eliminating this directivity diagram, two mutually perpendicular loops are used, in the form of slit airtight rings.

In recent years, for the reception of LF and VLF waves on foreign submarines magnetic loop antennas with ferrite cores have been used, combining ferromagnetic and dielectric properties (f = 100 kHz, $\mu = 2000$, $\sigma = 10^{-7}$ to 10^{-12} cm/m , $\varepsilon = 10$ to 20).

The effective height of the ferrite antenna is:

$$h_д = \frac{2\pi nS\mu_{эфф}}{\lambda}, \tag{6.3}$$

where $\mu_{эфф}$ is the effective value of the magnetic permeability.

Magnetic antennas are placed horizontally on the radio room's enclosure or inside it, have not too great dimensions and are used at any speeds of a submarine in the submerged or surface position. The antenna consists of a ferrite core on which is placed a coil enclosed in an electrostatic shield.

Since the effectiveness of the radio reception with a single ferrite core antenna is insufficient, several similar antennas are installed, connected in parallel in two mutually perpendicular groups. Because of this the total

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effective height of the antenna increases, an antenna diagram in the form of a figure eight is made possible, and with appropriate phasing it is possible to control this diagram, pointing its null toward the noise source.

As an example can be cited the ferrite antenna developed in Sweden for a type 43 submarine, which is installed on the stern section of the radio room's enclosure in a radome and is designed for the outside pressure when the submarine is submerged down to 500 m [91].

For the purpose of increasing the depth of submersion of a submarine for carrying out communications, in the USA special antennas and buoys have been developed. A buoy consists of two sections and has three antennas, including one for VLF reception. But these buoys as a rule limit the maneuvering capabilities of submarines and decamouflage them.

The most promising way of increasing the depth of underwater radio reception is thought to be the use of towed antennas, including antennas with positive buoyancy. One variant of this type of antenna has been developed for the Sanguine system [90]. This antenna is in the form of a horizontally towed cable with positive buoyancy and a total length of 530 to 610 m, on which are mounted two electrodes (fig 6.1c). The distance between electrodes is selected in such a manner as to reduce to the greatest degree the "electrical" interference which originates as the result of a change in the electrochemical activity (turbulence) of the water near the electrodes when the submarine is moving. For the purpose of damping the vibrations of the last electrode, the antenna ends in a damper, because of which the "high-speed" noise is reduced, which occurs because of the vibration of the antenna in the magnetic field of the moving submarine.

Since the length of the antenna is much greater than the wavelength, then the directivity diagram has the form of a figure eight. For the reception of magnetic vibrations a multi-turn solenoid coil has been suggested, wound in the form of a long spiral onto a ferromagnetic core. The directivity diagram of this antenna also has the form of a figure eight, but turned 90°. This combined antenna is shown in fig 6.1c. By means of phasing, it is possible to control the directivity diagram (fig 6.1d).

The positive buoyancy antenna on foreign submarines is structurally executed (fig 6.2) in the form of two layers of porous polyethylene, 1, with positive buoyancy and an outside diameter of 16.5 mm, a glass fiber coil, 2, consisting of 26 turns 0.97 mm in diameter, a layer of low-density polyethylene, 3, 7.1 mm in diameter, and four 20-strand copper insulated wires of medium hardness, crossed in pairs, 4, and covered with a high-density layer of polyethylene 1.5 mm in diameter. At the present time American specialists have settled on a receiving antenna length of 300 m. The most acceptable is considered a diameter equal to 2.57 mm.

Buoy-cable antennas with positive buoyancy, similar to those discussed, are used in the American navy for reception in the VLF and HF bands (cf. fig 6.1a and b) [90].

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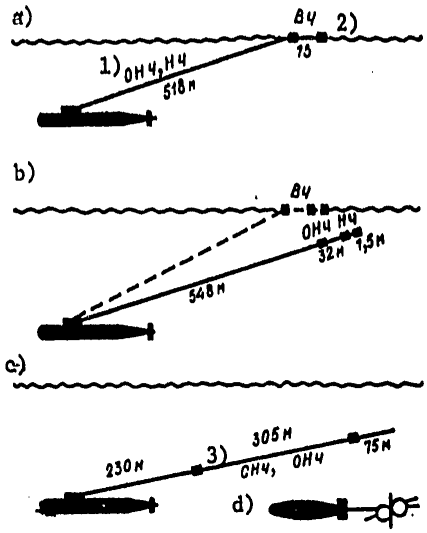

Figure 6.1. Types of Towed Antennas for a Foreign Submarine

Key:
1. VLF, LF
2. HF
3. ULF, VLF

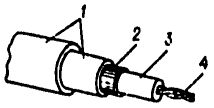

Figure 6.2. Cross Section of Positive-Buoyancy ULF Antenna

For enabling the operation of radio communications and radio navigation facilities when the submarine is at periscope depth, submarines are equipped with telescoping devices, the total number of which on a submarine reaches eight to 10. Telescoping equipment for an American nuclear torpedo submarine are shown in fig 6.3a [17]. Whip-type telescoping antennas emerge 4 to 8 m from the room of the enclosure, with a mast length of 10 to 14 m.

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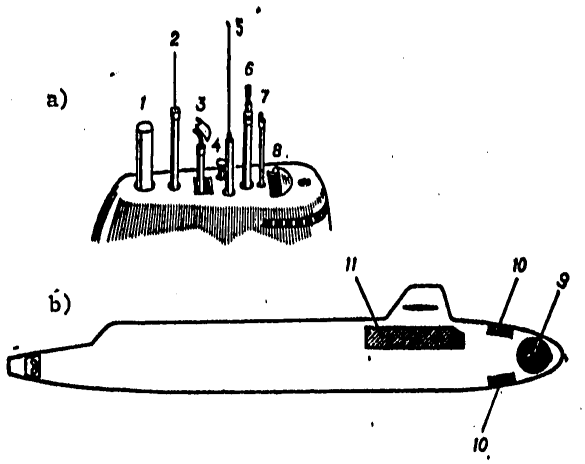

Figure 6.3. Location of Control and Communications Stations, Telescoping Equipment and Antennas on a Foreign Nuclear Submarine: 1--snorkel; 2 and 5--radio antennas; 3--active RLS antenna; 4--VLF antenna; 6--periscope with passive RLS antenna; 7--periscope; 8--bridge; 9--GAS [hydroacoustic system] long-range communications antenna; 10--GAS short-range communications antenna; 11--central station, radio room, hydroacoustic room and firing control station

On the type 43 diesel submarine (Sweden) there are six combined antennas and a single emergency whip antenna [91]. Nuclear rocket-launching submarines are equipped in addition with telescoping radio navigation and radio sextant antennas. Telescoping devices are arranged in two or three parallel rows, which makes it possible to reduce the length of the radio room's enclosure. The masts for telescoping devices, for the purpose of reducing wakes, are made with radomes made of aluminum-magnesium alloys, glass fiber reinforced plastics or Monel metal (alloy of nickel and copper), inside of which is run a high-frequency cable [5]. Telescoping devices are raised to the working position by hydraulic drives, and the system is lowered under the influence of the weight of the mast.

For the effective utilization of antennas over a wide frequency range, special antenna designs have been developed, e.g., ones partly made in the form of a coil. In changing from one frequency to another, the length of the antenna is changed by means of a sliding contact. The antenna is retracted in 40 s and operates in the 2 to 32 MHz frequency band [86]. The reversibility characteristic of antennas (reception-transmission) is extensively employed on

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submarines for the purpose of reducing their number. For example, for American submarines the type A/BPX combination receiving and transmitting antenna has been developed for HF and microwave radio communications and a target detection radar set [5].

For the purpose of excluding the influence of one antenna on another, a multi-channel system is employed, consisting of amplification and coupling devices and decoupling filters with a minimum frequency interval between adjacent channels. In addition, receiving and transmitting antennas are spatially separated and are placed in mutually perpendicular planes. Communications and radar antennas are not only spatially separated (by not less than 5 m), but are also electrically insulated from one another. An endeavor is made to spatially separate microwave antennas for different ranges, also.

The grounding of antennas on submarines is accomplished fairly simply. One of the output terminals of the transmitter or receiver is connected to the antenna, and the other to a wide copper busbar, whose other end is soldered to the ship's hull.

Whip antennas are employed as emergency antennas, which are placed on the enclosure of the radio room vertically or horizontally [17].

For the purpose of maintaining two-way communications in the submerged position at any navigation depth, on submarines is installed hydroacoustic communications equipment with its own antennas. The following are the specific requirements for the location of acoustic antennas: separation as far as possible from main sources of internal noise--propellers, rudders, auxiliary gear, etc.; installation in a radome protecting the antenna from oncoming water currents; the antenna must not be screened by the hull and structural elements of the submarine, must not distort the outline of the hull, and must not reduce the maneuvering and speed characteristics of the submarine.

The fulfillment of these requirements is achieved primarily by placing the antenna in a radome on the bow section of the submarine, in the form of a superstructure, or inside the outer hull flush with the plating. The first method of placement is typical of diesel electric submarines, and the second of nuclear. For making radomes metal is used extensively, and in recent years on American submarines, plastics, e.g., reinforced glass fiber reinforced plastic. The employment of plastics reduces noise interference, they do not corrode, they improve sound transmission over a wide range, and they reduce the weight and cost of structures.

Acoustic communications antennas (acoustic transducers) on foreign submarines operate as a rule in the reversible mode. They are made at the present time chiefly out of piezoceramics, since they have fairly high efficiency (50 to 70 percent), withstand high power levels and any pressure (when compensation of external pressure is employed), possess high sensitivity, do not change their parameters with an increase in depth and are relatively inexpensive.

The directional effect of acoustic antennas is characterized by axial concentration factors, γ , which are determined for a plane plunger-type of

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transducer by equation (3.26), for a cylindrical transducer by $\gamma = 2h/\lambda$ (h is the height of the cylinder), and for a spherical transducer by $\gamma = 1$.

The concentration factors for plunger-type and cylindrical transducers increase with an increase in frequency. In real antennas secondary maxima occur, as well as side lobes and different disturbances of the symmetry of the directivity diagram. In reception with a directional antenna it is possible to extend the communications range by concentration of the strength of the acoustic signal and improvement of the signal-to-noise ratio. But with a unidirectional antenna scan-free communications and the maintenance of communications between correspondents in motion are impossible, since the low rate of propagation of acoustic waves in water does not make it possible to make a quick scan of space and automatically track a correspondent. The directivity of communications is ensured by employing antennas of spherical or cylindrical shape.

A no less important parameter ensuring a specific communications range is the total and limiting unit radiated acoustic power. The obtainment of maximum acoustic power is substantially limited by the cavitation phenomenon (sec 3.2).

The communications range also depends on the sensitivity of the receiving antenna. With modern foreign piezoceramic transducers, the sensitivity reaches 1000 μV/Pa.

The frequency characteristics of an acoustic antenna depend on the material of the transducer, its design, dimensions, etc. For example, the resonant frequency of a cylindrical transducer equals $f_r = c_k/\pi d$, where c_k is the speed of sound in the piezoceramic and d is the diameter of the transducer.

In hydroacoustic communications equipment one strives to produce a uniform frequency characteristic over a wide frequency range. In broadband radiating elements the width of the passband $\Delta f = (0.1 \text{ to } 0.2)f_r$ with a relative power variation of up to 10 percent. For the purpose of producing a broader Δf it is necessary to use complex antenna designs. No less important is the noise interference characteristic of an acoustic antenna, N_k, whose magnitude depends on many factors (concentration of the antenna, its location, directional properties, communications frequency, magnitudes of noise from operating propellers and gear, hydrodynamic noise from the hull's radome and the antenna, etc.).

Transducers are usually created in the form of an array consisting of elements whose dimensions are determined by their f_r and whose number and location are determined by the required directivity. If it is necessary to have a directional acoustic antenna, then its dimensions must be small as compared with the wavelength, and in this case it is necessary to radiate high power levels per unit area of the antenna. The majority of radiating elements have limited dimensions comparable with the wavelength.

It was demonstrated above (sec 3.2) that hydroacoustic communications equipment has its own optimal operating frequency at which the maximum effective range is

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made possible, and any deviation from f_{opt} requires increasing the radiated power. In addition, it is necessary to take into account the fact that the majority of acoustic transducers are resonant devices and, consequently, operate effectively only at a strictly fixed frequency. In almost all foreign communications stations a standard carrier frequency equal to 8087 Hz is employed [55].

6.3. Principles of the Location and Design Features of Submarine Communications Facilities

In designing submarines and their radioelectronic equipment, there are certain specific requirements for communications facilities. Here are taken into account the point of location of radio and hydroacoustic rooms and antenna equipment; the amount of radioelectronic equipment (REA), its weight and overall dimensions; the power requirement of the communications REA; the interaction of communications facilities with other submarine facilities; the e.m.f. of communications facilities, between one another, with other REA, and with weapons; the capability for effective operation under conditions of mechanical and impact effects, vibration and the effect of temperature and moisture and ionizing radiation; the requirement of REA for cooling and ventilation; and convenience of operation and ease of repair [95].

The location of the radio room on the submarine is regulated as a rule by the location of control stations and antennas. At the central station (TsP) are concentrated the main stations and instruments enabling control of the ship and its weapons, and here is found the commanding officer. Therefore, the radio room must be placed in the direct vicinity of the TsP, the hydroacoustic room and the submarine's radio communications antennas. In fig 6.3b is shown the location of the TsP and of the hydroacoustic and radio room on an American nuclear torpedo submarine.

On nuclear submarines the REA takes up great inside space. As compared with submarines from the time of the Second World War, this space has increased three- to fourfold. The amount of hydroacoustic equipment has increased especially substantially. On submarines of the "Skate" and "Thresher" type the hydroacoustic equipment occupies 89 and 192 m^3, and the communications equipment, 12 and 42 m^3. All the key radio communications equipment is placed in the radio room, whose area equals 6 to 8 m^2. This same area is used for coding radio messages [5].

All the elements of radio equipment must have overall dimensions and weight such that it is possible to pass them through hatches. For ship REA in the U.S. Navy, standard racks are used with base dimensions of 457 X 457 mm^2 and a height of 1700 to 1880 mm. The weight of the REA of a submarine has been increasing steadily. For example, on submarines of the "Skate" type the weight of radioelectronic equipment equals 25 tons, and on submarines of the "Thresher" type, 62 tons, including, respectively (in tons): hydroacoustic equipment--19.8 and 54, radio communications equipment--2.5 and 4 [5]; and on submarines of the "Los Angeles" type the weight of the hydroacoustic complex equals 131 tons [73].

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It is obvious from this comparison that radio communications facilities on modern submarines continue to represent considerable weight and volume. Their further reduction, in the opinion of many specialists, can be achieved by the more extensive introduction of semiconductor devices and microelectronic elements.

Alternating current (in the USA, frequency of 60 Hz) is used to power the major users of electric power on modern foreign nuclear submarines. For powering radio communications equipment, an increased-frequency a.c. line is provided (120-220 V, 400 Hz) with voltage stabilization and a frequency not exceeding 0.5 to 5 percent of the rated.

The powering of radio transmitters is as a rule duplicated. The power requirement of radioelectronic facilities continues to grow; on a submarine of the "Thresher" type the total power requirement of REA is about 86 kW, including 54.2 kW for hydroacoustic equipment and 19.3 kW for radio communications facilities.

In developing communications facilities, provision is made for their interaction with other subsystems of the submarine, such as information sources, control stations and the submarine's weapons. It is possible to accomplish this by two methods: first, by making possible intraship communications by means of command relay equipment and ship telephone facilities; and, second, by means of organic communications between individual elements and blocks of equipment ensuring the rapid exchange of information, especially in digital form for feeding to a computer and the weapons system.

On American rocket-launching submarines eight relay subsystems are united by the first method. The central communications console of the shipwide command subsystem is installed at the TsP. All calls are automatically recorded by means of a tape recorder. It has been proposed that the intraship communications system be controlled by means of a computer.

The second method will be totally implemented with the introduction on a submarine of a military control and information system, e.g., of the SIES (Ships Integrated Electronic System) type, whereby the proposal is to create a single station for monitoring the good working order of REA; to unite radio communications and radio navigation antennas and hyroacoustic antennas used for observation and communications; to create a unified computing center for solving problems relating to the control of the submarine, analysis of the situation and the employment of radioelectronic equipment; and to create closed systems for the ventilation and cooling of REA, standardizing its elements, etc.

The problem of the e.m.f. of radio communications facilities in foreign fleets, between one another and with other radioelectronic equipment, has already been discussed in sec 6.2 and in chap 5.

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Under conditions of a submarine, there are special requirements for the effective operation of REA under mechanical and impact effects, vibration and the influence of temperature and moisture. The operating conditions for REA on a submarine outside the hull (antennas and feeder equipment) are severe, since antennas are constantly in sea water with micro-organisms and fairly sudden fluctuations in temperature and pressure inside the submarine are possible; in radio and hydroacoustic rooms operating conditions are average because of the influence of heightened moisture content, mechanical overloads and vibration.

In the conclusion of foreign specialists, REA in a submarine must be shock-proof and explosion-proof, especially with regard to underwater nuclear explosions. Impact effects are characterized by a magnitude whose value for REA must reach 15 to 50g [83]. An impact effect is most dangerous to brittle parts made of ceramics and ferrite, especially at their fastening points. For the purpose of protecting REA from impact overloads, the path has been chosen of improving the shock resistance of equipment: the employment of semiconductor devices instead of electronic tubes, of plastics instead of porcelain insulators, of bolted joints made of high-strength steel with a yield point of 60 to 80 kg/mm, the employment of soft rubber gaskets and lining (especially for antennas), and also the installation of equipment on shock absorbers. The natural frequencies of the shock absorbing system for REA must be two to three times lower than the lowest frequency of the disturbing force, and the vibration frequency of shock-proofed instruments, higher than the hazardous frequencies for the submarine's pressure hull (10 to 15 Hz), i.e., about 33 Hz. For shock-proofing lightweight REA, in the USA elastic spacers made of stainless wire are used. But American designers think that it is not advisable to install lightweight equipment on shock-proofing fastenings, since then the vibration frequency of the REA (8 to 16 Hz) will be close to the frequency of the fundamental vibrations of the submarine's hull, which can cause resonance and increase overloads in underwater explosions [91].

Air noise produced by working machinery not only worsens conditions for habitability, but also hampers the employment of intraship communications. According to USA standards, the noise level in service areas should not exceed 50 to 60 dB, which ensures distinct audibility of commands over the submarine's loudspeaker communications system. For the absorption of airborne noise, a sound-absorbing covering made of glass fiber reinforced plastic or polyurethane foam plastic is used, which reduces the noise level in proportion to the thickness of the covering [85].

REA on a submarine operates under conditions of elevated humidity. For example, on American nuclear submarines, with the air conditioning system shut off, in tropical waters the humidity has approached 90 percent, and the air temperature, 40 to 45°C [5]. Moisture penetrates all elements of REA and coats it with a very thin film of water (0.001 to 0.01 microns), which worsens REA parameters and disturbs its calibration and operation. For protection from the influence of humidity, sealing of individual assemblies is employed, along with protective coatings, linings, and, for partial desiccation, holders with silica gel. A change in ambient temperature exerts

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a considerable influence on REA elements, especially transistors. By American and English standards an air temperature of $t \leq 25°C$ has been set for living areas and stations (without restriction on humidity) and of $t \leq 30°C$ with 50 percent relative humidity [104].

In order to ensure stability in the operation of REA under heat effects under conditions on a submarine, extensively employed are thermal compensation, regulation of heat exchange between REA and the environment, individual and shipwide air coolers, and ventilating systems. In recent times on foreign submarines individual water cooling of REA has begun to be used, including for radio transmitters, as well as air conditioning systems [5]. The control equipment operates from temperature and humidity sensors located in compartments and rooms.

On foreign nuclear submarines the influence of ionizing radiation on REA elements is possible, which is caused by the proximity of radiation sources and the circulation of air in the shipwide ventilating system. Here it must be kept in mind that ionizing radiation has little influence on metal structures, and that organic materials are highly sensitive to radiation, and inorganic less so. REA elements are sensitive to the effect of radiation. Taking into account the danger of the influence of radiation on people and REA elements, American specialists have undertaken special measures against radioactive contamination (strict insulation of processes in which radiating materials take part, employment of an audio and light system for indicating radioactive emission, sampling of air and water, individual facilities for detecting radiation). In the opinion of American specialists, the radioactivity of the air must not exceed $6 \cdot 10^{-10}$ μcurie/cm^3 [93].

In considering questions relating to the convenience of employing REA under conditions on a submarine, much attention should be paid on one hand to the requirements of engineering psychology, and on the other to requirements for highly rapid discovery of malfunctions and for the ease of servicing of REA.

Special attention must be paid to questions relating to the arrangement of control and display consoles for REA on the submarine. For example, for foreign submarines it is recommended that the following requirements be fulfilled [85]:

That control consoles be arranged radially.

That the instruments at stations be divided into main and reference, that they be arranged in logical sequence, and that key instruments be in the center of consoles in a visible place.

That indicators requiring constant monitoring be placed at the eye level of operators within the limits of 30° below this level, and that instruments which are used by several people be located in the top half of consoles.

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That the scales of instruments be designed to be intelligible and that readings be clear and simple, and that for a lit indicator the contrast between markings and the background be not less than 1:5.

That indicators and their control knobs be oriented in relation to one another in a unified manner.

That controls be arranged conveniently for an operator of average height with average physical characteristics.

That room areas be illuminated with even non-contrasting lighting.

The question of the very rapid detection and elimination of malfunctions in REA is an important one. As already indicated, one of the objectives of the American SIES comprehensive ship's system is the creation of a single station for monitoring malfunctions in all the REA on the submarine, making it possible quickly and accurately to detect any malfunction.

For the purpose of improving the repairability and convenience of operation, it is necessary to standardize REA elements on the basis of the modular grouping principle. This principle proposes the creation of functional modules which are united according to a specific feature into an independent block, which is built into the overall design of the instrument and is connected to other blocks by external leads. In foreign marine REA four ranks of modules are used: the integrated circuit, the replaceable block (board, cassette), the instrument (rack), and the radioelectronic system (complex). This modular grouping hierarchy makes it possible not to repair, for example, modules containing integrated circuits, but with a "cold spare" to replace them with new ones, and to ensure the "self-healing" of REA during a specified period of operation under ship conditions on account of a "hot spare." The implementation of the modular design principle in American naval equipment has resulted in the fact that the percentage of integrated circuits in communications facilities as early as 1970 equaled 88 percent [88, 89].

We will discuss the equipment of submarines with communications facilities briefly, using the example of American submarines. The standard radio equipment of a submarine consists of the following elements:

Two type AN/WRR-2 HF receivers (2 to 30 MHz band), to which is entrusted the reception of single-band broadcasts in the audio, printing and facsimile telegraph modes [102].

One VLF radio receiver (in England this receiver operates in the 6 to 36 kHz band, the width of the passband is variable, suppression of image interference is greater than 80 dB, and selectivity is 50 Hz from the resonance curve) [73].

Two An/WRT-1 and AN/WRT-2 or AN/WRT-4 and AN/WRC-1 type transmitters with enhanced power and high frequency stability, enabling scan-free and trim-free communications in the 2 to 30 MHz band.

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High-speed equipment in the form of individual blocks with a storage unit, making it possible to transmit messages at a rate of 1000 words per minute [39].

Printing equipment for radio communications, with an electrostatic printing rate of up to 1000 characters per second [39].

Automatic message coding equipment [39].

It has been proposed to install ship satellite communications equipment on American submarines (cf. chap 5).

An experimental receiver has been developed for enabling the reception of messages at depths greater than 30 m, in keeping with the Sanguine project [90]. A block diagram of this receiver is shown in fig 6.4. The receiver consists of two blocks: an analog (preamplification and filtering) and a digital (further filtering, signal processing and dynamic control).

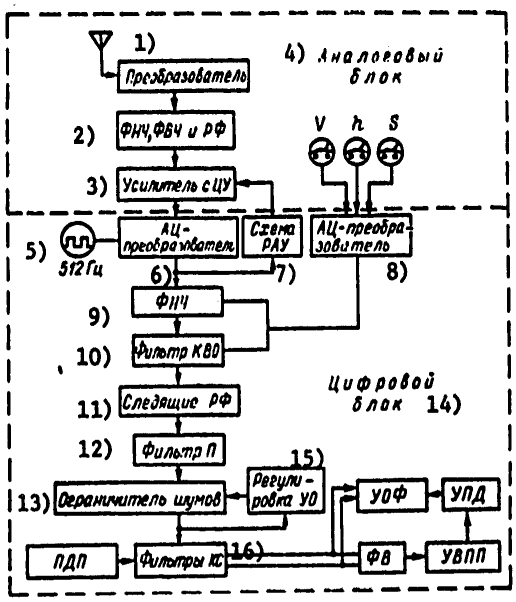

Figure 6.4. Block Diagram of ULF Radio Receiver: Amplifier with TsU--with digital control; KVO filter--filter for compensating influence of the ocean; P filter--predistortion filter; PDP--pseudorandom binary sequence; KS filters--quadrature matched filters; RAU circuit--analog amplification regulation circuit; UO adjustment--clipping level adjustment; UOF--phase evaluating unit; UPD--sequential decoding unit; FV--phase inverter; UVPP--primary sequence restoration unit

[Key on following page]

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Key:

1. Converter
2. FNCh [low-frequency filter], FVCh [high-frequency filter] and RF [rejector filter]
3. Amplifier with TsU
4. Analog block
5. 512 Hz
6. ATs [analog-digital] converter
7. RAU circuit
8. ATs converter
9. FNCh
10. KVO filter
11. Follower RF's
12. P filter
13. Noise clipper
14. Digital block
15. UO adjustment
16. KS filters

The receiver's analog block contains a universal system of filters which enables normal operation in the presence of different kinds of interference. The preamplifiers are protected by shields from electromagnetic interference from the power line and are mechanically isolated from the chassis, which eliminates vibrations at frequencies corresponding to its passband. The analog input circuit ensures steady gain (not less than 160 dB) in keeping with the level of atmospheric noise and the speed and depth of submersion of the submarine.

The signal is selected from the output of the analog block and is converted into digital form by the computer's analog-digital converter, which is also the receiver's base, and the selection time is determined from a precision clock. Signal processing of this sort at low transmission rates (one bit of information in 100 s) is the most economical.

The computer has a 16-kbit memory and an access time of 1 μs. The input signal is processed by the computer to take into account the speed and depth of submersion of the submarine and the time of day. Output information is processed by a simplified teletype at a rate of 30 characters per second.

The low-frequency filter excludes the passage of HF components of antenna noise, and the filter for compensating the influence of the ocean restores the atmospheric noise characteristic, which disappears with an increase in depth. Follower rejector filters reduce the level of interference from the submarine's motors (suppress a frequency of 60 Hz and its harmonics). The predistortion filter levels the atmospheric noise spectrum, and the noise clipper adaptively reduces the effectiveness of noise levels. Quadrature matched filters restore as much information as possible. Because of these measures, in this receiver a nearly optimal passband is obtained (about $4 \cdot 10^{-3}$ Hz). The phase evaluation unit (the error must be minimal, since it reduces the energy of the input signal by a factor equal to the square of the cosine of the phase error) estimates the phase from the signal itself at each level by interpolation. Reasons for a change in phase can be a sudden change in the submarine's depth and ionospheric disturbances.

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Sequential and resultant decoding were selected because they ensure the highest reliability of message reception with the lowest signal-to-noise ratio. The unit makes it possible to determine the error with high probability, and the error in this case is not printed out at the output.

Intraship communications on modern submarines are carried out by means of command relay equipment and the telephone. The intraship command relay communications system on American nuclear rocket-launching submarines, the AN/WIC, consists of the following subsystems: shipwide command; electromechanical combat section; emergency reports; ship control; intraship communications; escape hatch; rocket weaponry control; rocket compartment internal communications [5]. In addition, included in the system are an emergency alert signal generator, about 90 loudspeakers and 50 local communications stations. The delivery of emergency signals and control and monitoring of the system's operation are carried out from the central station of the shipwide system. The system permits the transmission of a radio broadcasting program and has a tape recorder for recording conversations on board the submarine. An emergency battery power supply is provided.

When sailing in the surface position, the submarine is controlled from the forebridge, employing the remote control console for surface travel, in which, in addition to instruments for controlling the submarine, there is also a command relay unit [5].

For the purpose of enabling telephone communications on submarines, there are batteryless telephones and automatic telephone switchboards with a capacity of a few dozen numbers [85].

Thus, the main method of exchanging information inside the submarine is microphone communications. But this method does not make possible the required traffic speed and much time is spent on receiving, recording and transmitting information. Considerably greater capabilities are had by multichannel television communications systems and electronic internal communications systems based on computers, employing telephone terminals, light pipe systems, etc. [93, 99, 102].

In designing submarines, special attention is paid to the development of emergency rescue equipment for rendering assistance to a submarine in trouble and for rescuing its personnel. Included among this equipment are communications facilities for sending signals from the submarine in trouble and for communicating with ships rendering assistance: an emergency signal buoy with a telephone, emergency buoys and an emergency signaling system.

An emergency signal buoy is in the form of a hollow float with positive buoyancy, equipped with a signal lamp and telephone and connected to the submarine's hull by a cable wire whose length is 15 to 25 percent greater than the maximum depth of submersion of the submarine. The telephone receiver is located in an airtight inside compartment.

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For the purpose of reporting the location of an emergency, U.S. nuclear submarines are furnished with radio buoys or an emergency signaling system. The type T-616 SRT radio buoy is ejected to the surface via the unit for firing blank cartridges. The radio buoy's weight is 3.6 kg, its length 990 mm and its diameter 76.2 mm. On the top of the buoy is installed a collapsible whip antenna, which, after the buoy floats up, straightens out under the effect of a spring, and the transmitter installed in the buoy begins to transmit a coded distress signal at a 1.43 m wave (243 MHz) for 14 h. A corner reflector can be installed on the buoy, which considerably speeds up scanning by means of a ship or airborne radar set [85].

For the purpose of transmitting signals for notifying about an emergency state of the submarine or about submersion to a depth greater than its safe depth, on American submarines since 1968 the SECT (Submarine Emergency Communication Transmitter) automatic emergency signaling system has been employed. The transmitter is located in a special buoy (there are two of them on rocket launchers and one on torpedo submarines), which is ejected and floats up when the submarine is at a depth greater than its safe depth and when the pressure in the submarine exceeds the established norm and if the unit's selector switch has not been changed by the operator to the required position for 2 h.

After it floats up, the transmitter first automatically transmits a formalized message at four frequencies, which is automatically received by the coastal system, and then performs the role of a homing beacon. The proposal is to install these same buoys in a new modification on submarines of the "Trident" type [82, 87].

In this book hydroacoustic communications facilities are not discussed in detail. Therefore, let us acquaint ourselves only with the fundamentals which form the basis for designing communications facilities for foreign submarines, deepwater devices and divers.

Hydroacoustic communications equipment (GAS) differs considerably from analogous radio communications equipment. But in the development of GAS know-how gained in the evolution and development of radio communications facilities has been utilized.

The key tactical parameter of GAS is the required communications range, which depends on the purpose and type of GAS. The maximum required range for hydroacoustic communications with submarines is usually limited to a few dozen kilometers, since at long ranges hydroacoustic communications drastically lowers its quality (signals are delayed and distorted, the information transmission rate is considerably reduced, the time for travel of messages is increased, etc.). The range of communications with deepwater devices is limited by the depth of the ocean (11 to 13 km), and the range of communications with swimmers and divers, by their traveling range, and it usually equals a few hundred meters.

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For hydroacoustic communications the frequency band from single numbers of Hz to 100 kHz is employed. Broadening of this band has made it possible to begin the practical mastery of, in addition to amplitude, frequency and pulse phase modulation and keying, frequency and time multiplexing of channels, the analog and discrete form of representation and the exchange of information by employing memory units in real time. It was stressed in chap 3 that GAS has its own optimal frequency for a specific communications range. In the majority of foreign communications stations a standard carrier frequency equal to 8.0875 kHz is employed. However in recent years a changeover to a lower frequency region has been observed.

Having become widespread are single-band telephony and telegraphy with suppression of the carrier frequency and upper sideband, which has made it possible to improve the noise immunity of communications and achieve long communications ranges. For example, in the English "Sonar 2010" type GAS the message is transmitted at one frequency and the pause is filled by another frequency 800 Hz apart, and there is a unit for detecting and correcting errors. Tests of this system have demonstrated that error-free reception is guaranteed 98 percent of the time under the most unfavorable conditions for the propagation of sound in water [96, 100].

It has been proposed to increase the effective range and improve the noise immunity of GAS by employing new coding methods and adaptive methods of modulation. Systems of this sort are implemented fairly simply by means of ordinary digital equipment employed in computers.

The standard GAS for the U.S. Navy and NATO for surface vessels, submarines and deepwater devices is the AN/VQC-1 ("Gertrude") close-range telephone communications station, which has a number of modifications. The radiated power is 100 W and its communications range 9 km [97].

More modern is the AN/BQA-2 long-range communications station, which is part of the AN/BQQ-2 hydroacoustic complex of American nuclear submarines. This station makes possible stable secret communications at considerable distances.

On submarines of the "Los Angeles" type under construction, the proposal is to install the improved AN/BQQ-5 complex, which will include the AN/BQS-13DNA station, which operates also in the hydroacoustic communications mode [56]. A characteristic feature of this equipment is the ability to ensure omnidirectional and narrow-beam communications in the telephony and printing mode, by employing message coding equipment. This station has an improved secrecy mode, SESCO (Secure Submarine Communication), and is constructed according to the modular principle, employing integrated circuits. The complex also includes multi-channel tape recorders of the UNQ-7 (two-channel) or UNQ-8 (seven-channel) type, which make it possible to record and reproduce all information received [97].

Abroad significant experimental studies are under way, aimed primarily at extending the range of hydroacoustic communications. For example, in the

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USA in 1967 an experimental station was tested, with f = 500 to 1500 Hz , and a communications range of 1300 km was reached in the telegraph mode, with a transmission-reception rate of six words per minute.

For the English navy the "Sonar 2008" telephone communications station has been developed, which enables operation in the single sideband mode with carrier suppression, and, as compared with the existing station, is capable of realizing communications over a longer range at all standard NATO frequencies [96]. It has been suggested that current GAS models be replaced with the equipment of this system. It can be coupled with ship speech converters and is designed on the block principle (four key blocks). The output block consists of several converters with a directional directivity diagram and enables high-power operation [100].

GAS which as a rule operates in the telephone mode with a range of 10 to 13 km [82] has also been installed in deepwater equipment.

Hydroacoustic communications for enabling diving operations is also involved in mastery of ocean and sea depths. In the U.S. Navy two methods of transmitting information are employed: with modulated signals (on the principle of analogous ship equipment), and by the direct transmission of human speech into the water [56, 73].

Foreign publications have noted that the employment of atomic energy in submarines and the rapid development of radioelectronics and weapons have to a considerable extent complicated the control of a submarine. The basis for automation has been computers, which have already become widespread on submarines. For example, for American submarines, in keeping with the Sabik project, a combined system for automatically controlling a submarine has been developed [85], in which united into a single whole are six main systems for controlling strategic and tactical weapons, movement, the navigation complex, radioelectronic observing, target designation and counteraction facilities, and communications facilities and systems ensuring the habitability of compartments. The last system has been called upon to ensure the best operating modes for internal and external communications facilities. It includes an automatic high-speed transceiver, coding and decoding equipment, and automatic units for storing and processing received messages and reconnaissance information, while distributing them to assigned addresses. In addition, the control of the microclimate in compartments is concentrated at this system's console.

Representing the logical continuation of the Sabik program is the work of the FRISCO (Fast Reaction Submarine Control) program--fast reacting concentrated control of a submarine. The main objective of this program is the optimal integration of all control circuits in a single complex, and on this basis a changeover to comprehensive planning of submarines. On "Trident" guided missile submarines the combined radio equipment includes four AN/UYK-20 computers, which represent the base of the complex and unite, as in the Sabik system, all internal and external communications systems [73]. The AN/UYK-20 computer is a typical ship computer in the U.S. Navy and has the following key characteristics: time required to perform addition operations--0.75 μs,

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multiplication--3.8 μs, logic operations--1.0 μs; bit configuration--16; capacity of main memory--8,000 to 65,000 words; 16 input-output channels; weight--51 kg; overall dimensions--61 X 45 X 51 cm; mean cycle between failures--2000 h.

The following are the main ways to improve models of communications facilities for submarines, in the conclusion of Western specialists:

The combining of communications facilities into unified systems.

The introduction into communications systems of computers, which should become the main unit for processing information, arranging communications, controlling communications facilities and antennas and forming and monitoring communications channels.

Further improvement of the range of radio and hydroacoustic communications, especially reception at great depths, by employing ULF and increasing the radiated power of transmitters.

The creation of equipment by the functional unit method with a common element base, employing modular designs and built-in systems for monitoring functioning and automatically finding malfunctions, which will ensure high reliability, small dimensions and simplicity in the servicing and repair of communications facilities.

The creation of a new secret HF communications system in the submarine to shore direction with a carrier frequency which can be changed pseudorandomly, with a broad radiation range (noiselike signals, including for hydroacoustic communications).

The employment of printing equipment enabling the automatic coding and decoding of messages.

The extensive introduction of equipment for communication via satellite.

The introduction of a combined electronic system based on a single ship computing center for solving problems relating to control and monitoring malfunctioning of all submarine radioelectronic facilities.

The universal introduction of a system for slant sounding of the ionosphere and for reading out optimal radio communications frequencies at the user's request.

Chapter 7. Organization and Utilization of Communications with Vessels and Ships

The organization of communications should cover all facilities and types of communications with vessels and ships. HF radio communications has the main burden, and it has been steadily increasing in recent years, which is explained by the small number of HF channels assigned to the marine mobile service,

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an increase in navigation intensity, and by a growth in fleets in terms of number.*

The improvement of long-range marine communications should include, along with the mastery and introduction of satellite and meteor reflection communications, the more effective utilization of HF radio communications by the employment of facilities operating in better noise-rejection modes (frequency telegraphy, relative phase telegraphy, single sideband, etc.). But required for this is good knowledge of the organization and utilization of communications with vessels, especially of long-range communications in the shore to ship and ship to shore directions. Questions relating to the organization and utilization of communications at sea are strictly regulated by international documents, such as by radio communications regulations, conventions, etc., as well as by radio communications rules and other guiding documents of Soviet fleets [38, 53, 54, 59, 61, etc.].

7.1. Roadstead Communications

Roadstead communications are intended for traffic between vessels and ships and the shore within the boundaries of sea ports, in open and enclosed sea roads, and also in approaches to ports. Roadstead communications represent primarily microwave radio communications in the telephone mode, which enables traffic at a distance of 40 to 60 km and more. For example, MRKh vessels have been instructed to carry out roadstead communications when approaching ports, port stations and fishery combines having an on-shore radio station at a distance of less than 12 miles [1]. It is forbidden to conduct radio traffic on MF and HF; all conversations regarding the order of vessels on the road, approaches to berths and other questions are carried out only on microwave.**

The frequencies for radio traffic for ship to shore, between ships and in the harbor are governed by the decision of the worldwide administrative radio conference on the marine mobile service and are given in [61].

In a number of countries roadstead communications are carried out in the 100 to 150 m band, but because of the heavy loading of this band its use for roadstead communications has been curtailed in recent years.***

*For 150,000 vessels in the worldwide fleet there is a total of 907 channels, i.e., on average 166 marine radio stations operate in a single frequency band [72].

**HF operation for an A2-oscillation radio transmitter is stopped at a distance of 10 miles, and of an A1-oscillation, of 5 miles from a coastal station [63].

***This band was selected in order for small craft to be able to have a single radio transmitter for roadstead and navigation communications.

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On roadsteads, and especially in a harbor, visual communications facilities are widely employed between vessels and the shore, and in foreign ports or for communication with foreign vessels signal flags are preferable, communications with which in keeping with the international signal code considerably simplifies the conduct of traffic.

When vessels and ships sail near the coast, of great effectiveness can be coastal retransmitters operating in the microwave band, especially if they create a continuous communications zone enabling communications at a distance of r from the shore (fig 7.1). If r is given (e.g., by the position of the fairway), then the distance between retransmitters on the shore, d (cf. fig 7.1) will equal:

$$R = b_1 + b_2 = r \operatorname{ctg} \alpha_1 + r \operatorname{ctg} \alpha_2 = r (\operatorname{ctg} \alpha_1 + \operatorname{ctg} \alpha_2).$$

The calculation of communications ranges, r_1, r_2, r_3, ..., as a function of the heights of the location of retransmitters, H_1, H_2, H_3, ..., is described in chap 2.

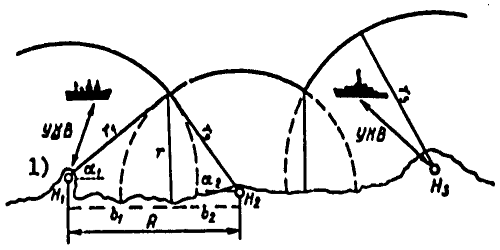

Figure 7.1. Microwave Communications Zones for Ships and Vessels When Sailing in a Coastal Area

Key:
1. Microwave

7.2. Communications Between Vessels and Ships and the Shore

Radio communications of a vessel or ship outside the range of roadstead communications are called navigation-and-operating communications in the MMF and radio communications with the shore in the MRKh and VMF. It is divided as a function of the range of radio routes into close-range and long-range.

When a vessel crosses 600 to 800 km radio communications are carried out in the MF band, and in the HF band with greater distances. Communications in the MF band are as a rule telegraph (A1 mode), and in the HF band, telegraph (A1 mode), printing (F1 mode) and telephone.

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A vessel in sailing at distances from the shore of up to 800 km comparatively easily establishes and carries out radio communications with radio stations, by operating at the needed, and often high, powers of its radio transmitters. This method of communication is not rational in areas of heavy navigation with a large number of coastal stations, since much interference is created. Therefore, coastal radio station zones have been established, within the limits of which a vessel can carry out communications with only one specific station--the zone station guaranteeing the vessel transit of its correspondence.

The defining of zones and coastal radio stations must ensure over the entire area of the sea the transmission of marine correspondence to any destination point with a minimum number of retransmission points. As a rule a two-stage system is achieved, which is considered the most reasonable in the maritime fleet [11, 63]. The communications zones for coastal stations with vessels in a sea basin are shown in fig 7.2. When necessary, vessels can establish direct communication with stations of another zone for the purpose of transmitting routine information, e.g., traffic control information to the port of destination.

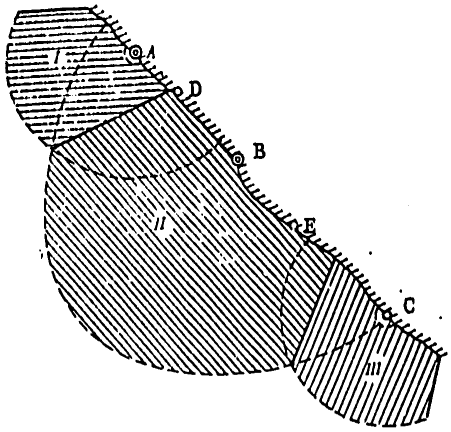

Figure 7.2. Communications Zones for Coastal MF and HF Stations, for Vessels in a Sea Basin; A, B, C--radio stations of ports for which communications zones I, II, III have been established; D, E--radio stations of not too large ports not having communications zones

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When vessels sail at great distances (more than 800 km), for purposes of uniformly distributing the load of coastal stations and of ensuring continuous monitoring of their position, it is also advisable to establish zones for communications with vessels in the HF band. Then they reach great dimensions.

In defining communications zones and coastal radio centers for servicing these zones, it is necessary to strive to ensure maximum flexibility in carrying out communications, i.e., the vessel should have the ability to establish communications and conduct traffic not with one, but with two or more points (which is very important when a vessel is in areas with poor travel of waves) or with a single RTs [radio center] of the vessel's choice. In fig 7.3 are shown approximate zones for HF communications with vessels completing voyages from ports of the Baltic and Black seas to ports of Western Europe and North Africa [63]. From the region enclosed in triangle VGO, a vessel can conduct radio traffic with any RTs of two communications zones, which increases the probability of communications between the vessel and the shore.

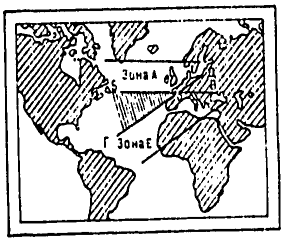

Figure 7.3. Communications Zones of Coastal HF RTs's, for Vessels in Long-Range Navigation

When communicating with a single RTs, a vessel accomplishes radio communication with a probability of P_{H1}. With radio interference the probability of communication can be increased by multiple simultaneous transmission of the message. But with heavy radio interference or with the poor travel of radio waves it is necessary to transmit the message n times at different frequencies or at various times.

The following is suggested for estimating the probability of a vessel's communicating with several receiving (transmitting) points, the number of receiving (transmitting) points, and the number of message transmissions.

There are k receiving points, at each of which a message arrives (signal, call, radiogram) from a vessel with probability P_1, i.e., equally probable reception by all points is accomplished. It is necessary to find the probability of communications: 1) with a single transmission of a message and its reception by any of k points; 2) with n transmissions of a message and

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its reception by one of k points; 3) with a single transmission of a message and its simultaneous reception by two, three, ... , m points of k points; 4) with n transmissions of a message and its reception by 2, 3, ... , m points out of k points.

The number of transmissions from a single vessel is not too great, and with territorially spaced reception each point receives independently of the others. Therefore it can be assumed that the distribution of probability of communication obeys a binomial law. Consequently, for the conditions used, the probability of communication in the single transmission of a message and reception of it by any of k points equals $R_1 = 1 - (1 - r_1)^k$. The probability of communication with n transmissions and reception by any point equals $r_1 = 1 - (1 - P_1)^n$.

With the reception by any of k points of a message transmitted n times, the probability of communication, R_1 , becomes equal to $R_1 = 1 - (1 - r_1)^k = 1 - \{1 - [1 - (1 - P_1)^n]\}^k = 1 - (1 - P_1)^{nk}$.

The necessity for simultaneous reception by two or three and more points is determined by the aspiration of improving fidelity by comparing messages received.

In a general formulation, the solution of this problem boils down to finding P_m , the probability of communication in the reception by m points out of k^m of a message transmitted n times:

$$P_m = C_k^m r_1^m (1 - r_1)^{k-m} = C_k^m [1 - (1 - P_1)^n]^m (1 - P_1)^{(k-m)} .$$

Hence it follows that the probability of communication in the simultaneous reception by two or more points out of k of one of n transmissions from a vessel, R_2 , equals:

$$R_2 = 1 - R_0 - R_1 = 1 - (1 - r_1)^k - k r_1 (1 - r_1)^{k-1} = 1 - (1 - P_1)^{nk} - k [1 - (1 - P_1)^n] (1 - P_1)^{n(k-1)}.$$

As a result of a transform, we get the equation:

$$R_2 = 1 - k (1 - P_1)^{n(k-1)} + (k - 1) (1 - P_1)^{nk}.$$

In a similar manner it is possible to calculate the probability of communication in simultaneous reception by three or more points out of k of one of n transmissions from the vessel, R_3 :

$$R_3 = 1 - R_0 - R_1 - R_2 = 1 - (1 - P_1)^{nk} - k (1 - P_1)^{n(k-1)} - k (1 - P_1)^{nk} - C_k^2 (1 - P_1)^{n(k-2)} + 2C_k^2 (1 - P_1)^{n(k-1)} - C_k^2 (1 - P_1)^{nk} = 1 - C_k^2 (1 - P_1)^{n(k-2)} + (2C_k^2 - k) (1 - P_1)^{n(k-1)} - (C_k^2 - k + 1) (1 - P_1)^{nk};$$

$$R_3 = 1 - C_k^2 (1 - P_1)^{n(k-2)} + (2C_k^2 - k) (1 - P_1)^{n(k-1)} - (C_k^2 - k + 1) (1 - P_1)^{nk}.$$

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Calculation of the values of R_2 and R_3 from the equations arrived at, and more so the values of k with assigned values of p_1, R_2 and R_3, is rather complex. To make it easier, the authors have calculated the graphs shown in fig 7.4.

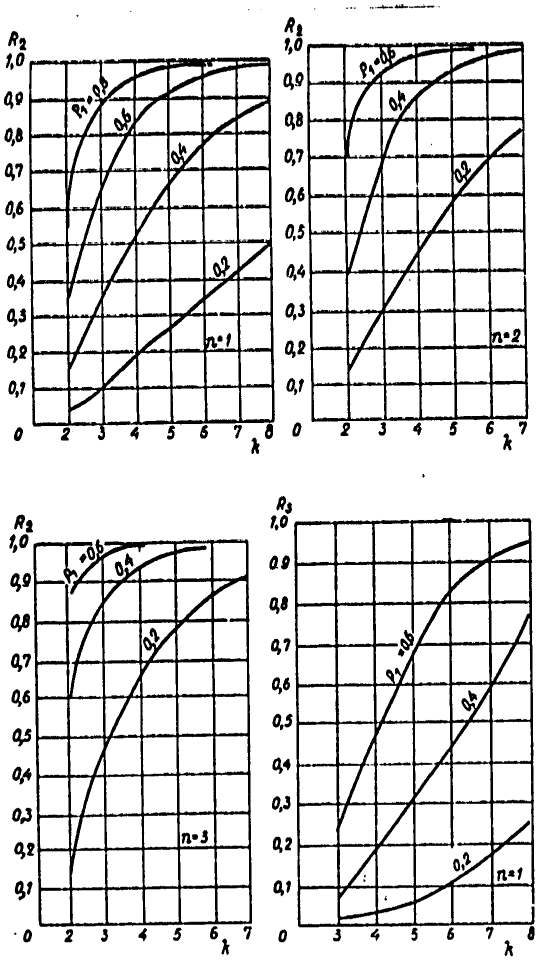

Figure 7.4. [Continuation and caption on following page]

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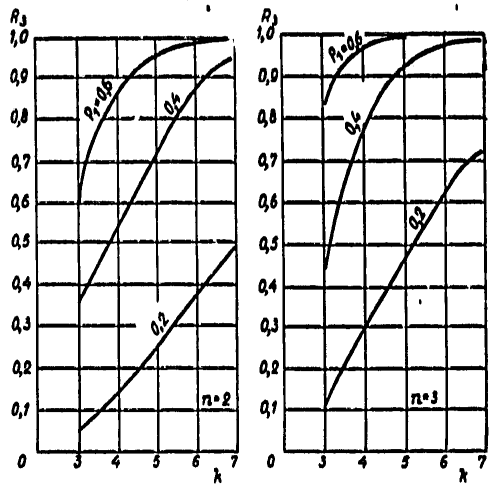

Figure 7.4. Graphs of Dependence of the Probability of Simultaneous Reception by Two (R_2) and Three (R_3) Points from Number of Points (k) of Transmissions (n) and of Individual Probability of Reception (P_1)

In a similar manner can be calculated the probability of communication with variation in the number of transmitting points and with two-way communication between the vessel and different numbers of receiving points and transmitting points in the communications system. By using graphs, it is possible to calculate also the required number of transmissions of a message, n , for anticipated conditions of communications, P_1 , and for specific requirements for R_2 and R_3 in a communications system having k transmitting (receiving) points, i.e., k communications zone radio centers.

It is obvious that of k communications zone radio centers one must be the main center and the others secondary (auxiliary). Taking into account the fact that the greatest difficulties for long-range communications with vessels are presented by the reception on shore of messages transmitted by a marine radio transmitter having, as a rule, not too great power, most often auxiliary receiving points are installed on shore, e.g., in the English communications system, whose communications zones are shown in fig 7.5. The entire global ocean is divided into regions (communications zones), in each of which there are regional (i.e., main for the region in question) transceiving stations and additional (auxiliary) receiving stations [63]. A message is transmitted by the vessel in the HF band to a regional radio station located in the country to which the message is sent, or to the nearest regional or auxiliary radio

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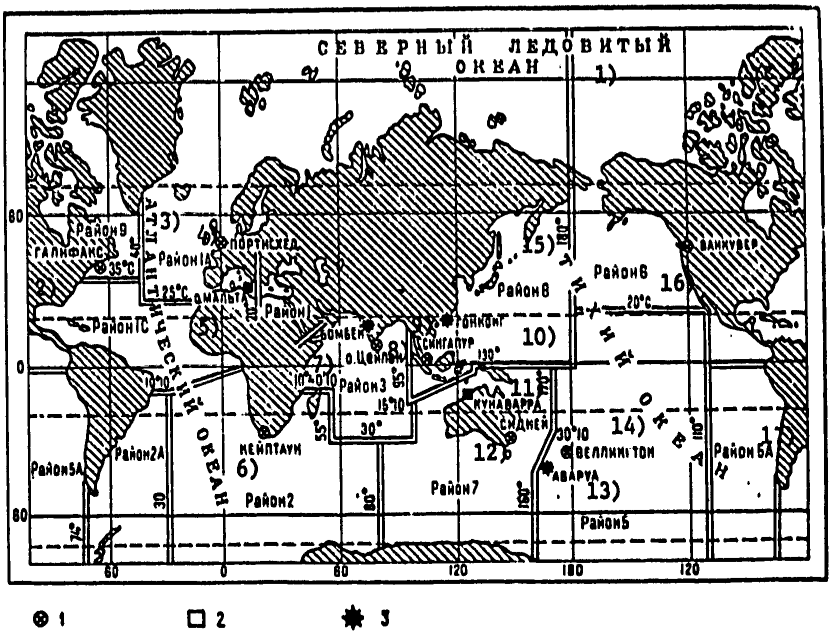
station. The message is transmitted to the addressee by tranait from regional or auxiliary stations.*

Vessels, in sailing, systematically send information to their shipping line (port of assignment) and port of destination.



⊗ 1 □ 2 ✱ 3

Figure 7.5. Communications Zones of English Coastal Radio Stations for HF Communications with Vessels: 1--regional transmitting and receiving station; 2--auxiliary receiving station; 3--regional receiving station

Key:

1. Arctic Ocean
2. Halifax
3. Atlantic Ocean
4. Portishead
5. Malta
6. Capetown
7. Bombay
8. Ceylon
9. Singapore
10. Hong Kong
11. Kunawarara
12. Sidney
13. Awarua
14. Wellington
15. Pacific Ocean
16. Vancouver
17. Region 5A

*In addition to English vessels, this communications system can be utilized by vessels of other countries, but additional payment is exacted from them for the use of coastal radio stations taking part in exchange of correspondence.

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Messages are transmitted to long-range navigation vessels by the main RTs's in whose zones they find themselves. Therefore, vessels have the obligation of reporting on their position to main RTs's every two 24-hour periods they remain at sea, as well as when entering a port or when leaving it. All coastal RTs's broadcast at the same time and only for single 24-hour periods, which is a considerable disadvantage of this communications system, since a vessel usually has a single radio receiver and can hear the broadcasts of a single RTs. For the purpose of improving the reliability of communications, it is necessary to increase the number of radio receivers on a vessel and for radio centers to make broadcasts at different times according to a schedule. Communications administrations are drawing up an operating time schedule for coastal and marine radio stations of the maritime and commercial fleet.

In long-range navigation vessels can use international radio communications also, although, as is obvious from table 1.1, the number of international radio messages in information flows comprises fractions of a percent.

Coastal stations are in service continuously day and night, if possible. However, some, as a rule not too large, stations operate at restricted times.

Marine radio stations, in conformity with international radio communications regulations for length of duty, are divided into four categories: Stations of category 1 are in continuous service; stations in category 2 are in service 16 h per 24-h period (0000 to 0400, 0800 to 1200, 1600 to 1800 and 2000 to 2200 hours marine or zone time and 4 h for marine communications needs); stations of category 3 are in service 8 h out or 24 h (0800 to 1200, any two hours continuously between 1800 and 2200 of marine or zone time, and 2 h for marine communications needs); and stations of category 4 are in service less than 8 h and their operating time is not regulated.

Each communications administration itself determines the rules according to which marine stations are divided into the appropriate categories, but by taking into account the requirements of international radio communications regulations.*

For the purpose of establishing radio communications by marine stations of category 2 and 3, between one another and with the shore, a unified schedule for the operation of these stations has been introduced by international regulations. For this purpose the entire global ocean is divided along meridians into 24 zones, A, B, C, D, ..., Z , as illustrated in fig 7.6, and for each zone a unified schedule has been established for the operation of stations of category 2 and 3 [61].

Radio communications between vessels and coastal radio stations are established at definite call frequencies, and then traffic is carried out at fixed

*In the Soviet marine radio service all marine stations operate according to definite schedules, which take into account international requirements [63].

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frequencies. The distribution of frequencies is one of the most important questions; therefore, let us dwell briefly on it.

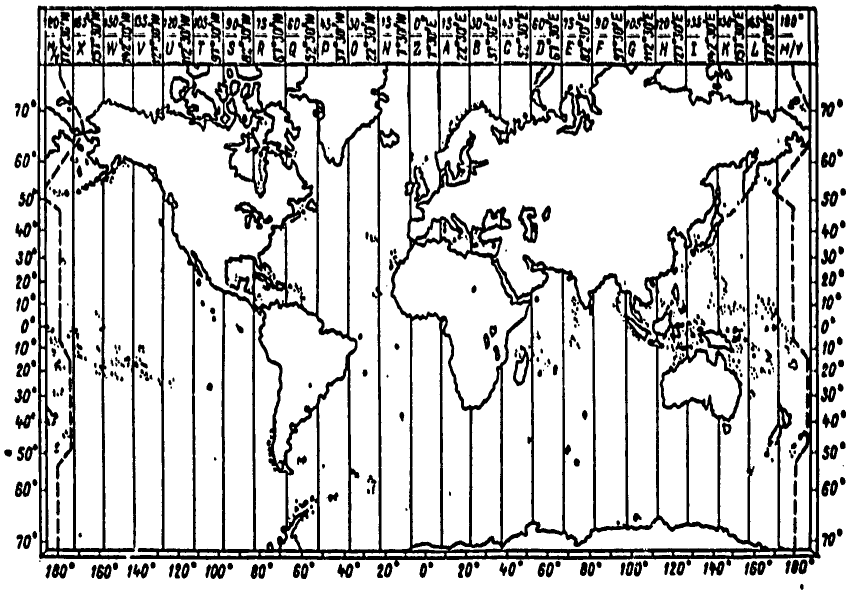

Figure 7.6. Radio Service Zones and Time for Vessels of Category 2

The entire range of frequencies used for radio communications, by decision of the MKKR, is divided into nine bands, indicated in Appendix 2. These bands have been divided by international agreements into bands which have been assigned to various radio services: a) the stationary service, i.e., the service for radio communications between stationary ground points; b) the mobile service, i.e., the service for radio communications between mobile and ground stations or just mobile stations on vessels, aircraft, automobiles, etc.; c) the marine mobile service, i.e., the service for radio communications between marine and coastal stations, as well as between marine stations; d) the airborne and other services.

For the purpose of distributing radio frequencies, the entire world is divided into three regions, as illustrated in fig 7.7. The boundaries of these regions are lines A, B and C. The distribution of frequency bands by services has been done for the entire world and for regions. In table 7.1 frequency bands are indicated only for the mobile service, by the conventional designation PS, and for the marine mobile service, by MPS. MPS stations in the 4 to 27.5 MHz range have been assigned frequency bands of 4, 6, 8, 16, 22, 25 and 27 MHz. The first six are divided into 13 segments [61], each of which is used for different regulated purposes and classes of transmission (duplex, simplex

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radio telephony, Morse code telegraphy, digital selective call, etc.), as indicated, for example, in table 7.2. The purpose and employment of each frequency range are given in the regulations [61]. Let us dwell briefly only on the 405 to 535 kHz range. In this range are transmitted, as a rule, distress, urgency and security signals, notifications from navigators regarding hazards at sea, etc. Therefore, strict requirements for the utilization of frequencies in this range have been provided by international rules and the radio communications rules of Soviet fleets.

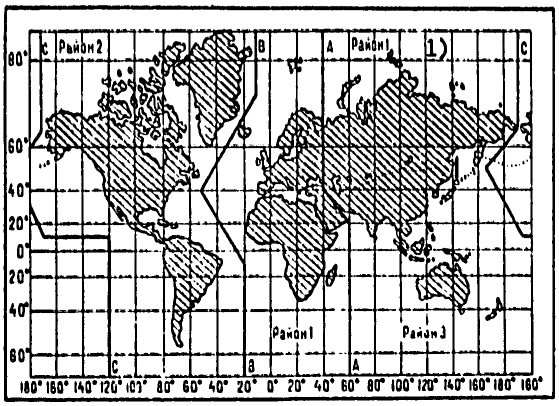

Figure 7.7. Charts of Regions Provided in Table of Distribution of Frequency Bands

Key:

1. Region 1

In this range only sustained and tone oscillations (A1, A2 and A2N) are permitted to operate. Communications between coastal radio stations and vessels, as well as between vessels, must be carried out with minimum power of radio transmitters. The most important frequency in this range is 500 kHz--the international call and distress frequency. It is employed by marine vessels and aircraft when immediate assistance is required and for the transmission of urgency and security signals and messages. Coastal stations are permitted to use this frequency for calls and responses to them, for selective calling, and for communications regarding forthcoming transmission of lists of call vessels for which there is correspondence.

Each coastal radio station operating in this band must have, in addition to a frequency of 500 kHz, not less than one operating frequency. Marine stations have been assigned the use as operating frequencies of 425, 454, 468 and 480 kHz, and in regions 1 and 3, 512 kHz, and in region 2, 448 kHz [61]. The frequency of 512 kHz can be used by coastal and marine stations for calling, when the 500 kHz frequency is occupied by traffic for questions relating to vessels in distress.

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Table 7.1.

1) Полоса частот, кГц	Всемирное распределение 2) частот	Районное распределение частот		
		3) 4) Район 1	Район 2	Район 3
1	2	3	4	
90—110	— 5)	МПС и др.	МПС и др.	МПС и др.
110—130	—	110—112, 115—126, 129—130 МПС и др.	МПС и др.	МПС и др.
130—160	-	МПС и др.	МПС и др.	МПС и др.
255—285	—	МПС и др	"	"
405—415	-	6) ПС и др.	—	—
415—490	МПС	—	—	—
490—510	ПС (сигналы бедствия и вызова) 7)	—	—	—
510—525	—	МПС и др.	ПС и др.	МПС и др.
1605—2170	—	ПС и др.	ПС и др.	ПС и др.
2170—2194	ПС (сигналы вызова и бедствия) 8)	ПС и др.	ПС и др.	ПС и др.
2194—2625	—	ПС и др.	ПС и др.	ПС и др.
2625—2850	—	МПС и др.	ПС и др.	ПС и др.
3155—3400	ПС и др.	—	—	—
3500—4000	—	ПС и др.	ПС и др.	ПС и др.
4063—4650	МПС и др.	—	—	—
6200—6525	МПС	—	—	—
8195—22720	МПС	—	—	—
25010—25110	ПС и др.	—	—	—
25110—27500	ПС и др.	—	—	—

Key:

1. Frequency band, kHz
2. Worldwide distribution of frequencies
3. Regional distribution of frequencies
4. Region 1
5. MPS, etc.
6. PS, etc.
7. PS (distress and call signals)
8. PS (call and distress signals)

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Table 7.2.

1) Полосы, МГц	2) Участки полосы, количество частот (N), разнесенные через Δf (кГц), присваиваемые видам морской связи		
	3) Широкополосная телеграфия, факсимиле, специальные системы передачи (Δf = 4 кГц)	4) Передача океанографических данных (Δf = 0,3 кГц)	5) Узкополосная телеграфия (буквопечатание и передача данных) со скоростью до 100 бод (Δf = 0,5 кГц)
4	4 148,6—4 160,6 N = 4	4 162,9 — 4 165,6 N = 10	4 350 — 4 356,5 N = 14
6	6 226,6—6 242,6 N = 5	6 244,9 — 6 247,6 N = 10	6 494,5 — 6 505,5 N = 23
8	8 302—8 326 N = 7	8 328,4 — 8 331,1 N = 10	8 705 — 8 718 N = 27
12	12 441,5—12 477,5 N = 10	12 479,9 — 12 482,6 N = 10	13 071,5 — 13 099,5 N = 57
16	16 598,4—16 634,4 N = 10	16 636,9 — 16 639,6 N = 10	17 197,5 — 17 231,5 N = 69
22	22 142—22 158 N = 5	22 160,9 — 22 163,6 N = 10	22 561,5 — 22 594,5 N = 67

Key:

1. Bands, MHz
2. Band segments; number of frequencies (N) spaced over Δf (kHz) assigned to types of marine communications
3. Broadband telegraphy, facsimile, special transmission systems (Δf = 4 kHz)
4. Transmission of oceanographic data (Δf = 0.3 kHz)
5. Narrowband telegraphy (printing and data transmission at a rate of up to 100 bauds (Δf = 0.5 kHz)

For the purpose of establishing radiotelegraph communications, a marine station uses one of the band's call frequencies (in each band are provided 2 common and 4 group channels and additional call frequencies [61]), selecting the best one in terms of propagation conditions. Coastal stations conduct watches on common call channels (in each band) and assigned group channels in conformity with the data in the list of coastal stations and respond to calls at their frequency. They call vessels at definite hours at the frequency designated on their operating schedule. Vessels respond at their own call frequency in the same band.

After the establishment of communications at the call frequency, the calling station shifts for the transmission of correspondence to one of its own operating frequencies (as, for example, in table 7.3), since traffic at call frequencies is not permitted. The frequencies for bands between 4 and 27.5 MHz are given in [61]. Coastal stations in A1 and F1 transmission operate at a power of not greater than 5 kW (4 to 6 MHz) and 15 kW (12 to 22 MHz).

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Table 7.3.

1) № серии	2) Полоса 8 МГц		5) Полоса 12 МГц		6) Полоса 16 МГц	
	3) Береговые станции	Судовые станции 4)	Береговые 3) станции	Судовые станции 4)	3) Береговые станции	Судовые станции 4)
1	8705	8344	13 071,5	12 491,5	17 197,5	16 660,5
2	8705,5	8344,5	13 072	12 492	17 198	16 661
3	8706	8345	13 072,5	12 492,5	17 198,5	16 661,5
4	8706,5	8345,5	13 073	12 493	17 199	16 662
. . .	. . .	. . .	. . .	. . .	. . .	. . .
27	8718	8357	13 084,5	12 504,5	17 210,5	16 673,5
. . .			. . .	. . .	. . .	. . .
57			13 099,5	12 519,5	17 225,5	16 688,5
69					17 231,5	16 694,5

Key:

1. Number of series
2. 8 MHz band
3. Coastal stations
4. Marine stations
5. 12 MHz band
6. 16 MHz band

For the purpose of establishing radiotelephone communications, marine and coastal stations use carrier frequencies (table 7.4) or assigned operating frequencies [61]. The frequencies and operating time of coastal stations are given in the list of coastal stations. For the conduct of traffic by coastal and marine stations, a determination has been made of carrier and assigned frequencies for single-band transmission for duplex and simplex operation [61], and the number of channels gotten thereby is given in table 7.4. In duplex operation with AZA and AZJ transmission, the power of coastal stations must be not greater than 10 kW, and of marine, 1.5 kW, and with simplex operation the power of stations must not be greater than 1 kW.

Printing radio communications with vessels is similar in terms of the procedure for establishing communications and for conducting traffic to radiotelephone communications, discussed above. First communications is established between the vessel and the coastal radio station, and then traffic is conducted at operating frequencies [61]. In this manner are radio communications carried out between MMF and MRKh vessels and their radio centers (communications units). Major and secondary MMF and MRKh radio centers and the operating areas of these radio centers are given in [43, 51].

Vessels and ships at sea obligatorily receive hydrometeorological communications and notifications from navigators regarding hazards discovered at sea, regarding changes or malfunctions in buoyage at sea, communications regarding fairways, etc.

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Table 7.4.

1) Полоса частот, МГц	Вызывные частоты, кГц		Количество в полосе рабочих каналов	
	2) Береговые станции 4)	Судовые станции 5)	3) двухчастотных для дуплексной работы (№ канала) 6)	одночастотных для симплексной работы 7)
4	4 419,4	4 125	26 (401—426)	1
6	6 521,9	6 215	6 (601—606)	2
8	8 780,9	8 257	31 (801—831)	2
12	13 162,8	12 392	32 (1201—1232)	3
16	17 294,9	16 522	41 (1601—1641)	3
22	22 658	22 062	40 (2201—2240)	5

Примечание: Для вызова используются частоты каналов 421, 606, 821, 1221, 1621, 2221. 8)

Key:

1. Frequency band, MHz
2. Call frequencies, kHz
3. Number of operating channels in band
4. Coastal stations
5. Marine stations
6. Two-frequency for duplex operation (number of channel)
7. Single-frequency for simplex operation
8. Note: For calling, frequencies of channels 421, 606, 821, 1221, 1621 and 2221 are used.

Lists of coastal stations transmitting these communications, their call letters, operating frequencies, transmitting times, and the nature of communications transmitted to the USSR are published for the information of all navigators in "Information for Navigators," published by the VMF Hydrographic Administration. Data on stations of foreign governments are published in "List of Stations for Radio Identification and Special Services," published by the International Telecommunication Union.

The organization of communications for foreign vessels, as demonstrated by analysis, is similar to that discussed, but there are distinctive features, the major one being the following. Soviet vessels as a rule maintain communications with their own shipping lines and administrations, and in the case of difficulty in carrying out direct communication, or of its absence, traffic is conducted via any other RTs, including the MMF or MRKh central communications unit (TsSU). Foreign vessels transmit information not to the vessel's owner, but to the nearest coastal radio station, from which it is transmitted to the addressee through the quite ramified "Telex" network. In this system distances between a vessel and a coastal radio station rarely exceed 2000 to 5000 km, unlike in the domestic system, where they reach 10,000 to 20,000 km [72].

7.3. Communications of Vessels and Ships in Joint Navigation

Vessels of the MRKh fleet as a rule work according to the expedition system in a fishing ground. Ships of the VMF, when fulfilling set objectives, in

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the majority of instances work jointly. MMF vessels not infrequently sail together in a group, e.g., as part of a convoy. When vessels and ships sail together, communications are carried out not only with the shore, but also with one another.

The organization of communications between vessels and the shore remains fundamentally the same as that discussed in sec 7.2. But the employment of communications is modified somewhat. Vessels and ships receive information from their own units, and traffic is conducted by the flagship or squadron vessel.

Vessels and ships maintain direct communication with the flagship, which regulates their radio traffic. Communications between vessels is called commercial in the MRKh, and tactical in the VMF. The organization of communications of this sort entails communication times, frequencies, operating period, and nature of traffic.

Communications between MMF vessels in towing, piloting through ice, or in a convoy are conducted, depending on distances, in the microwave, MF or HF bands.

Commercial radio communications are carried out usually over not too great distances of 300 to 400 km. For this, the microwave band is used (F3 mode) and the 1.6 to 3.8 MHz HF band (A3 mode), enabling communications with good travel of radio waves at any time of day. Over long distances, radio communications are carried out in the HF band according to a preset schedule. Communication between vessels is as a rule radiotelephone (mode F3 and A3). By its means are conducted commercial conferences between squadrons regarding organization of the catch and the advice of flotilla chiefs and fleet specialists is conveyed, and circulating broadcasts are made of the results of grounds reconnaissance, instructions are given on the order of vessels, and the like.

Communications in each group of vessels are carried out at the operating frequency fixed for this group of vessels. For enabling calling and watching in the area of grounds, the so-called fleetwide call frequency [1] has been assigned, at which radio stations watch depot ships and emergency rescue vessels.

Tactical communications between ships has undergone considerable development in recent years. For simultaneous control of the maneuvering of ships, their weapons and facilities in joint navigation and when fulfilling objectives, as well as for the exchange of information on questions relating to changes in situation and to their operations, as a rule several radio networks are set up in the microwave and HF bands, depending on communications ranges. Furthermore, their number has been growing steadily. According to the data of English studies, this increase has occurred in the following manner. Whereas for small ships one network was required in 1945, in 1955 two were required, and in 1965, four; for larger ships, whereas two were required in 1945, in 1955 four were required, and in 1965, eight. Thus, every 10 years a 100-percent increase has occurred in the number of radio networks.

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In interaction between surface ships and aircraft, direct two-way radio communications between them is necessary. In many instances on ships only the reception of reports is required, but directly from reconnaissance aircraft. In the opinion of English specialists, communications along a ship-to-aircraft link is now required for practically every ship of a fleet, not to mention aircraft carriers, which must have 20 such communications channels for the control of aircraft in the air, for bringing them home and for enabling landing. The majority of the latest English destroyers and frigates have helicopters, and some of these ships have been entrusted with special tasks relating to the control of fighters. Therefore, all ships must have the ability to communicate with aircraft, even if these are PVO [air defense] or PLO [antisubmarine defense] aircraft and they are under the jurisdiction of the VMS [naval forces] aviation command or shore command. Direct radio communications is arranged for, as a rule, in an individual radio network and, in relation to distances, in the microwave or HF band.

In speaking of communications between vessels and ships, mention must also be made of transit marine and ship stations. In carrying out communications with the shore, a vessel with a low-power transmitter (e.g., vessels of the commercial fleet of low and medium tonnage have a 200 W transmitter) sends its information to vessels having steady radio communication with coastal RTs's, which transmit it to the destination. As these intermediaries--transit radio stations--are used large-tonnage vessels equipped with powerful transmitters and highly sensitive receivers.

However, with this sort of retransmission a delay in communications occurs and added distortion is possible. Free of these disadvantages are radio relay stations, e.g., the one installed on the American carrier "Redwood," which is used simultaneously as a supply ship and a floating radio relay station.

Widely employed in the U.S. Navy are the radio communications and relay ships "Annapolis" and "Arlington," by means of which at the time of the war in Vietnam communications were carried out between ships and TOF [Pacific Ocean Fleet] and U.S. Navy headquarters [102].

7.4. Communications with Vessels and Ships in Long-Range Navigation

Vessels and ships completing long voyages are in constant communication with their own communications units, and, besides, vessels can in individual cases carry out communications with stations of a number of countries. More than 1500 coastal radio stations in all countries of the world serve navigators. A description of foreign radio stations which can be used by Soviet vessels on the Leningrad-Odessa route, from ports of the Black and Baltic seas to Cuba, to ports of Africa, South America and Antarctica, as well as to Vladivostok, is given in the list of coastal stations in [51, 63].

Depending on their position, Soviet vessels always maintain continuous communication with one or more reference points in the Soviet Union, in particular, with Moscow, Leningrad, Odessa and Vladivostok.

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Moscow maintains communications chiefly with vessels in regions considerably remote from European bases (the Atlantic and Indian oceans, the Antarctic Basin, the South Korean and East China seas).

Leningrad carries out communications with vessels of all shipping lines at distances up to the Bay of Biscay, and with BMP [marine batallion] vessels in the Mediterranean, Black and Red seas, in the Indian Ocean and in the East China and South China seas.

Odessa maintains communication with vessels of all shipping lines in an area from the eastern boundaries of the Indian Ocean to the Bay of Biscay and the central section of the Atlantic Ocean, and with ChMP [marine unit] vessels along the entire route from the Baltic and North Seaas and the Norwegian Sea to the western half of the Pacific Ocean.

Vladivostok maintains communication with vessels of all shipping lines in regions of the South China Sea and eastern half of the Indian Ocean, and with DVMP [marine force] vessels to the Red Sea and eastern half of the Mediterranean Sea.

Watch over calls and the transmission of correspondence are performed in definite bands and at definite times.

All radio centers in the 6, 8, 12 and 16 MHz bands operate round the clock, with the exception of the Moscow RTs, at 6 MHz only from 1900 to 0730 hours, and at 16 MHz from 0800 to 1900 hours, the Odessa RTs at 16 MHz in the day, and the Vladivostok RTs does not operate at 16 MHz. In the 22 MHz band only the Odessa RTs operates, in the daytime. In communications with Moscow, vessels use the frequencies assigned to them and transmit their communications to it. Odessa and Vladivostok also are in operation--they monitor calls and receive correspondence from vessels at the operating frequencies of their own RTs's. Leningrad watches calls from vessels at their frequencies and at these same frequencies receives communications from vessels, and transmits information to vessels at the operating frequencies of the RTs.

It is recommended that vessels select frequencies in relation to the area in which they are sailing and the time of year and day, guided by table 7.5, developed on the basis of the data presented in [63]. This table confirms the conclusion regarding the advisability of combined utilization of coastal RTs's for communications with vessels and ships located in different areas of the global ocean in relation to the time of year and day, as well as to conditions for the travel of radio waves.

Communications between U.S. Navy ships and the shore are organized and carried out in the shore to ship and ship to shore directions.

In the shore to ship direction, communications are transmitted by communications units, at which communications arrive from control agencies along

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trunk communications lines.* Broadcasts to ships are carried out by three methods: radio broadcasting, the radio interception method (an intermediary), and the acknowledgement method. In the first two methods ships just receive all broadcasts, and in the last they transmit an acknowledgement in confirmation of the receipt of a radio message. The radio broadcasting method is the main one. The entire global ocean is divided into regions. For ships located in these regions broadcasts are made by the communications units indicated in fig 7.8. Broadcasts are made according to set schedules at a single VLF or LF frequency and on up to five in the HF band [94].

Table 7.5.

1) Район плавания	2) Время суток	3) Качество связи	Рекомендуемые частоты (МГц) для связи с радиоцентрами (4)							
			5) РЦ Москва				6) РЦ Ленинград			
			7) Весна	8) Лето	9) Осень	10) Зима	Весна	Лето	Осень	Зима
Норвежское море, Северное море, пролив Ла-Манш 11)	12) Ночь	удовлетворительное	—	—	—	6, 8	12	—	12	—
		хорошее	6, 8	6, 8, 12	6, 8	—	6, 8	6, 8, 12	6, 8	6, 8
	13) День	удовлетворительное	—	—	—	12, 16	—	6	16	16
		хорошее 15)	12, 16	12, 16	12, 16	—	8, 12, 16	8, 12, 16	8, 12	8, 12
Центральная часть Атлантического океана, Карибское море, Мексиканский залив 16)	Ночь	удовлетворительное	12	12	12	12	12	12	12	12
		хорошее	—	—	—	—	—	—	—	—
	День	удовлетворительное	—	—	16	12, 16	—	—	16	12, 16
		хорошее	12, 16	16	—	—	12, 16	16	—	—
Бискайский залив, Гибралтарский пролив, западная часть Средиземного 17)	Ночь	удовлетворительное	—	6	—	—	6	6	—	12
		хорошее	6, 8, 12	8, 12, 16	6, 8, 12	6, 8, 12	8, 12	8, 12	6, 8, 12	6, 8

[Continuation on following page]

*Trunk communications are carried out through printing (RATT), audio telephone (CW) and facsimile telegraph (FAX) communications channels of the VMS system and leased TCW service (provided by telephone companies). By means of route indicators (letter groups) are indicated global communications networks or networks of a theater or region and the kind of armed force, such as the navy, land forces, or air force, the geographical region where the station is located, U.S. Navy main, auxiliary and lower-level radio stations, the coding station, the delivery section or other communications unit sections.

Radio communications trunk lines in the U.S. Navy are of the following types: 1) semiduplex (NDKh); 2) duplex (FDKh); 3) multiplex (MIKh)--a multichannel

[Footnote continued on following page]

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Table 7.5. [Continued]

моря 18)	День	удовлетворительное	—	—	8	—	8, 22	—	—	12, 16
		хорошее	8, 12, 16	12, 16	12, 16	12, 16	12, 16	12, 16	12, 16	—
Восточная часть Средиземного моря, Красное море, западная часть Индийского океана 19)	Ночь	неустойчивое 21)	—	—	—	—	—	—	—	—
		удовлетворительное	—	—	—	8, 12	8, 12	—	8	8
		хорошее	8, 12	8, 12	8, 12	8	—	8, 12	8, 12	8
	День	неустойчивое	—	—	—	—	—	—	—	—
		удовлетворительное	—	—	—	16	12, 16	—	12, 22	16, 22
		хорошее	12, 16	12, 16	16	12	—	12, 16	16	12
Восточная часть Индийского океана, Южно-Китайское море 20)	Ночь	удовлетворительное	—	—	12	8, 12	12	—	8, 12	12
		хорошее	8, 12	12, 16	—	—	—	12, 16	—	—
	День	неустойчивое	—	—	—	—	12, 16	—	22	12, 16, 22
		удовлетворительное	12	—	—	—	22	—	16	—
		хорошее	16	—	—	—	—	16	—	—

[Continuation on following page]

communications line in which each message is distributed over separate channels, and channels are combined by means of time distribution at a single carrier frequency; and 4) a single sideband communications line (SSB), enabling simultaneous transmission and reception in six to 16 teletype channels and in one or more microphone channels in the upper or lower side band. Widely employed for trunk communications is the "Autodyne" automated digital communications system, which is discussed in greater detail in the third section.

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Table 7.5. [Continued]

1) Район плавания	2) Время суток	3) Качество связи	4) Рекомендуемые частоты (МГц) для связи с радиоцентрами							
			22) РЦ Одесса				23) РЦ Владивосток			
			7) Весна	8) Лето	9) Осень	10) Зима	Весна	Лето	Осень	Зима
Норвежское море, Северное море, пролив Ла-Манш 11)	12) Ночь	удовлетворительное	—	—	—	—	—	—	—	—
		хорошее	6, 8, 12	6, 8, 12	6, 8, 12	6, 8	—	—	—	—
	13) День	удовлетворительное	6	—	—	—	—	—	—	—
		хорошее	8, 12, 16	12, 16	8, 12, 16	8, 12	—	—	—	—
Центральная часть Атлантического океана, Карибское море, Мексиканский залив 16)	Ночь	удовлетворительное	12	12	12	12	—	—	—	—
		хорошее	—	16	—	—	—	—	—	—
	День	удовлетворительное	—	22	12	12	—	—	—	—
		хорошее	16, 22	—	—	—	—	—	—	—
Бискайский залив, Гибралтарский пролив, западная часть Средиземного моря 17) 18)	Ночь	удовлетворительное	—	16	—	12	—	—	—	—
		хорошее	6, 8, 12	6, 8, 12	6, 8, 12	6, 8	—	—	—	—
	13) День	удовлетворительное	6, 22	8	8, 22	8	—	—	—	—
		хорошее	8, 12, 16	12, 16, 22	12, 16	8, 12, 16	—	—	—	—
Восточная часть Средиземного моря, Красное море, западная часть Индийского океана 19)	12) Ночь	21) неустойчивое	—	—	—	—	8	—	12	—
		удовлетворительное	—	6	—	—	12	12	—	12
		15) хорошее	6, 8, 12	8, 12	6, 8, 12	6, 8	—	—	—	—
	День	неустойчивое	—	—	—	—	—	—	16	16
		удовлетворительное	—	8, 22	22	10	16	16	—	—
		хорошее	12, 16, 22	12, 16	8, 12, 16	8, 12	—	—	—	—
Восточная часть Индийского океана, Южно-Китайское море 20)	Ночь	удовлетворительное	8, 12	—	12	8, 12	—	8, 12	—	—
		хорошее	—	12, 16	—	—	8, 12	16	8, 12	8, 12
	День	неустойчивое	12, 16	—	—	12	—	—	—	—
		удовлетворительное	—	—	12	—	—	—	12	16
		хорошее	—	16	16	—	12, 16	12, 16	16	—

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Key:

1. Sailing area
2. Time of day
3. Quality of communications
4. Recommended frequencies (MHz) for communications with radio centers
5. Moscow RTs
6. Leningrad RTs
7. Spring
8. Summer
9. Fall
10. Winter
11. Norwegian Sea, North Sea, La Manche Strait
12. Night
13. Day
14. Satisfactory
15. Good
16. Central section of Atlantic Ocean, Carribean Sea, Gulf of Mexico
17. Bay of Biscay, Gulf of Gibraltar, western half of Mediterranean
18. Seas
19. Eastern half of Mediterranean Sea, Red Sea, western half of Indian Ocean
20. Eastern half of Indian Ocean, South China Sea
21. Unstable
22. Odessa RTs
23. Vladivostok RTs

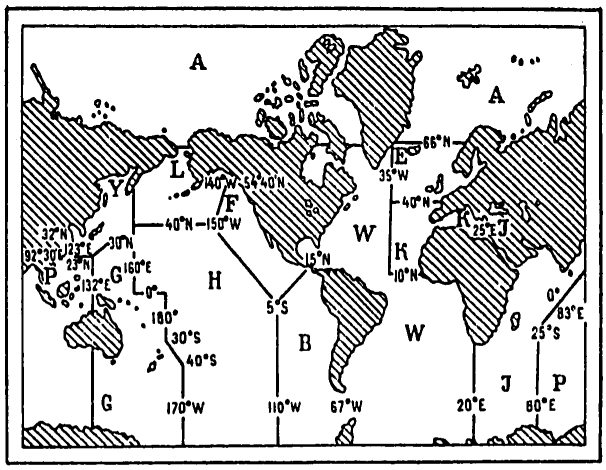

Figure 7.8. U.S. Navy Communications Regions for Broadcasts by the Radio Broadcasting Method: A--arctic; E--London-Derry; K--Port Liote; W--Washington; J--Asmara; Y--Yokosuka; L--Kodiak; F--San Francisco; H--Pearl Harbor; P--Phillipines; G--Guam; B--Balboa

Usually audio telegraph radio broadcasts for the fleet begin at 00 min of each hour and continue for not more than 50 min. The duration of conference broadcasts has been increased to 1 h 50 min [94]. Ships usually receive simultaneously at two frequencies—in the VLF and HF bands or only in the

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HF band. For transmission are employed automatic radio telegraphy (at a transmission rate of up to 29 words per minute), printing and facsimile telegraphy. Ships and vessels having printing equipment do not receive audio telegraphy.

These same communications units perform conference broadcasts, which include hydrographic warnings, notices to navigators, information for commercial vessels, and weather reports. In certain regions ordinary radio broadcasts also contain storm warnings and time signals [94].

In the ship to shore direction communications are carried out through main, secondary and special communications lines [94]. When necessary, ships use these lines.

Main lines are used for long-range communications in the ship to shore direction. The choice of frequencies is made by a ship on the basis of tables of radio wave propagation or by monitoring of broadcasts in the HF band by the communications unit with which it is necessary to establish communication. A ship usually transmits messages in the audio radio telegraphy mode. For the purpose of transmitting messages by printing or facsimile telegraphy, a ship first establishes communications through audio telegraphy and transmits a service radio message--a request, in accordance with which the coastal unit prepares for printing or facsimile telegraphy reception.

Secondary lines are used instead of main lines when a ship is at not too great distances from coastal and port radio stations, communication with which is carried out in the audio telegraphy mode at MF band frequencies. Via these coastal radio stations the ship transmits the required communications to control agencies. If the secondary communications line is used for port (roadstead) communications, then the ship is on watch constantly in this case.

Special lines are set up upon an order from headquarters in the fulfillment of an objective. In this case coastal radio stations go on watch duty, which do not usually do so in the ship to shore direction.

Telephone conversations of commanding officers and staffs of formations and of commanders of large ships are conducted through "Autovon" automated radio telephone communications systems, and "Autosevcom" closed-circuit radio telephone conversation systems [39, 68].

In peacetime headquarters can permit ships to use the commercial radio telephone communications service, which enables telephone conversations through commercial ground radio stations by naval force ships with any user on shore. Here only ships make calls. It is not permitted to call ships.

At not too great distances radio telephone communications are made possible by close-range radio telephone communications stations located at centers in Astoria-Portland, Boston, Charleston, Galveston, Jacksonville, Miami, etc. Communications with ships on the open sea are made possible by long-range

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radio telephone communications service stations located in Oakland (California), New York and Miami [94].

The fee for telephone conversations depends on the location of the ship and the land user; for this purpose, coastal waters are divided into tariff regions, and the entire surface of the globe into three land and three ocean tariff regions [94].

Individual naval ships, e.g., the communications ships "Annapolis" and "Arlington," the aircraft carriers "Wasp" and "Midway" and the cruiser "Canberra," for communications with the shore utilize communications through a satellite communications system and through leased channels of commercial satellite communications systems [39, 68]. But this is still of an experimental nature.

7.5. Communications with Submarines and Deepwater Equipment

Communications with submarines has its own distinctive features, which must be taken into account in the control process.

The following are the requirements for a system for controlling submarines: the capability of timely transmission of information to submarines in the submerged position at great depths in any area of the global ocean; the capability of timely receipt of reports from submarines; the ensurance of high secrecy in the control of submarines in the ocean; the ability to maintain the ability to operate in the event of an enemy attack with ordinary and nuclear weapons; resistance to the influence of active radio interference and interference originating in high-level nuclear blasts [21, 39].

Communications with submarines is customarily discussed in terms of the communications routes along which the exchange of information is carried out.

The main requirement in the shore to submarine direction is reliability of communications. For the purpose of ensuring reliable communications, even during the time of the Second World War information was transmitted from the shore simultaneously at VLF and several HF frequencies. A submarine, depending on the situation, accomplishes reception in the surface position or at periscope depth in the HF and VLF bands, and in the submerged position, as reported by foreign publications, at depths down to 30 m, in the VLF band [21, 37]. For the purpose of ensuring high secrecy, information is transmitted to submarines selectively, by the no-acknowledgement method, and radio messages are numbered continuously.

The volume of radio messages and the length of communication sessions must be limited.

For reliable radio communications with submarines in the submerged position, superhigh-power VLF and ULF radio transmitting centers (PDRTs's) are required.

The key characteristics of VLF PDRTs's are presented in table 7.6. The key elements of VLF and ULF radio communications centers are the antenna complex

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and unique high-power radio transmitters. The antennas of VLF PDRTs's are structurally different. One of the variants of an antenna system arrangement is shown in fig 7.9.

Table 7.6.

Name of VLF or ULF PDRTs	Location	Power, kW	Frequency, kHz	Belongs to
Sanguine	Austin area (Texas)	10,000	0.45-0.75	USA (planned)
"	Lake Calm area (Wisconsin)	0.120	0.45-0.75	USA (experimental)
Annapolis	Washington area (Maryland)	1000	15.10	USA
San Francisco	San Francisco area	500-1000	15-54	USA
Jim Creek	Seattle area (Washington)	1000	14-35	USA
Cutler	Cutler Peninsula (Maine)	2000	14-30	USA
Balboa	Panama Canal Zone	1000	18-54	USA
San Diego	San Diego area	500-1000	17-54	USA
Harold Holt	North West Cape	1000-2000	16-20	USA
Guam	Guam			USA
Pearl harbor		1000	18-23.3	USA
Anthorn	Solway Firth, England	550	16-20	England
Rugby	Southeastern section of England	350	16.17	NATO, England
Krigion	Ditto	25-350	15.18	England
Malta	Malta	500	---	England

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Table 7.6. [Continued]

Name of VLF or ULF PDRTs	Location	Power, kW	Frequency, kHz	Belongs to
Tokyo	Tokyo area	400	15.17	Japan
Ste. Assis	Paris area	500-800	16.18	France
Varberg	Varberg area	200	17.18	Sweden

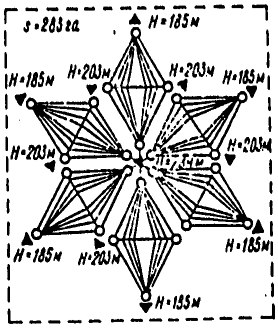

Figure 7.9. Arrangement Plan for VLF PDRTs Antenna System

Let us discuss briefly some modern VLF PDRTs's built by the USA in recent years. The most ideal is the "Cutler" PDRTs, whose power is 2000 kW. This center is located on the Cutler Peninsula (east coast of the USA) and is designed for transmitting information to nuclear guided missile submarines of the "Polaris-Poseidon" system found in the North Atlantic, the Arctic and the Mediterranean Sea. The radio transmitter consists of four amplifying stages which operate in pairs in the 14 to 30 kHz band (1000 kW each) with two antenna systems. The radio sets are powered by a diesel electric power plant with a capacity of 12,000 kW. Development of the project and construction of the center cost 70 million dollars, 20 million dollars of which were spent on construction of the antenna field.

The center's two antenna systems are suspended on 26 masts in the form of two hexagonal arrays. Each array is formed with six rhombic sections whose vertices are fastened to a center mast 300 m high. The opposite vertices of the sections are attached to six masts 240 m high each, with the distance between them equaling 1.7 km. The midpoints of the sections are supported by a cable suspended on six intermediate masts 270 m high each. The grounding system is made of copper busbars, is laid at a depth of 30 cm, and occupies an area of about 12 km^2.

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The following are the dimensions of certain parts of the antenna structures: height of attenuation coil--12 m, diameter--5.5 m; height of variometer used for tuning--6 m, diameter--3.6 m. The antenna system withstands a wind velocity of up to 67 m/s. A special system has been provided for deicing the antenna, which makes it possible in 30 min to melt away ice 5 cm thick. The efficiency of the antenna system is 50 percent [37].

The "Harold Holt" PDRTs was built in 1967, is located in West Australia on the North West Cape, and is designed for controlling guided missile submarines sailing in the Pacific and Indian oceans. The antenna system consists of a center mast 388 m high and of two ring sections surrounding it. The inner section has six tower masts each 365 m high, and the outer section six masts each 305 m high. The antenna is capable of withstanding a wind force with a velocity of up to 900 m/s. Electric power comes from a power plant with a capacity of 18,000 kW. The range of communication with submarines is up to 12,850 km [21].

It is obvious from the above that in the construction of high-power radio centers much attention is paid to the antenna field and to grounding, and at high-power stations several grounds are made. If the soil has low conductivity and grounding does not make possible good contact with the soil, then a counterweight is employed--a system of conductors suspended at a height of 1.5 to 2 m above the surface of Earth.

But coastal VLF radio centers equipped with enormous unshielded antenna systems are very vulnerable. Therefore, the development of the current VLF communications network for the U.S. Navy is proceeding along the direction of improving its stability and of ensuring communications over great distances and to great depths by employing a shielded "Sanguine" coastal ULF radio center and VLF radio relay equipment.

The proposal is to spend 750 million to 1.5 billion dollars on designing and creating a "Sanguine" system in the Austin area (Texas) [82, 86]. It has been decided to convert the experimental center in Wisconsin (on Lake Calm) into a proving ground.

In addition to the "Sanguine" system, other more economical ULF systems are also being planned. For example, the "Seafarer" system (cost, 500 million dollars), the PVS (Propagation Validation System), and the "Shelf" system (Super Hardened ELF) [90].

A rough plan of the arrangement of the antenna complex and transmitters in the "Sanguine" system is illustrated in fig 7.10. The transmitting antenna consists of orthogonal antenna arrays (fig 7.10a). The transmitters are located at the area of intersection of the antenna's perpendicular elements at a depth of more than 10 m in strengthened capsules and are connected by an antenna cable at a depth of 1.8 m with the four neighboring stations. The antenna field has an area of 75 X 150 = 11,250 km^2 [21].

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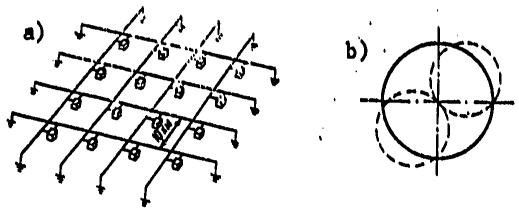

Figure 7.10. Arrangement Plan and Directivity Diagram of "Sanguine" System Transmitting Complex

In the system are employed 100 transmitters of 100 kW each, employing tubes and semiconductors. The total power supplied to the antenna system is 10 MW. Each capsule contains two power amplifiers--one for the north-south line, and another for the east-west. This system for arranging the antenna and connecting transmitters has redundancy, and an automatic commutation system restores the antenna array, maximizing the total current factor, if the capsules or antenna lines become damaged.

The radio center's ULF antenna consists of long sections of horizontally positioned cable whose ends are grounded. This antenna is equivalent to a single-turn loop with an effective area, in square meters, of [73]:

$$S_{э\phi\phi} = L\frac{\gamma}{\sqrt{2}}, \tag{7.1}$$

where L is the effective length of the antenna; $\gamma = 1/\sqrt{\pi f \mu_0 \sigma_e}$ is the "skin depth"--the depth of penetration of the current, in m; and $\mu_0 = 4\pi \cdot 10^{-7}$ is the magnetic permeability of a vacuum, in Gs/m.

The direction of the reverse current in such an antenna is parallel to the surface of the ground and the greater part of this current, because of the skin effect, travels within zones close to the ground surface. It is obvious from equation (7.1) that the reverse current penetrates the ground more deeply, the lower the conductivity of the soil, and, consequently, the radiated power is inversely proportional to the effective conductivity of the ground.

The most effective radiation of electromagnetic waves takes place when the dimensions of the antenna are commensurate with the wavelength. On this basis, for radiation at $f = 75$ Hz, for example, an antenna would be required with $L \sim 4000$ km, which is entirely unrealistic, and therefore the efficiency of these antennas is still very low: $\eta_{ULF} \approx 1 \cdot 10^{-4}$ (for comparison let us recall that $\eta_{VLF} \approx 0.5$ to 0.7).

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Since antennas for the ULF band are much shorter than the lengths of the waves radiated by them, the directivity diagram has the form of a figure eight.

The mutually perpendicular arrangement of groups of the antenna's parallel elements gives an omnidirectional directivity diagram and improves S_{eff} ; if currents in each of these groups are phased, then it is possible to control the directivity diagram (fig 7.10b).

The radiated power, P_R (W) , of a group of parallel elements can be calculated as follows:

When the antenna is at the surface of the ground or at not too considerable a depth:

$$P_R = \frac{\omega^2}{8c^3 H_i \sigma_e} (JL)^2; \tag{7.2}$$

When the antenna is in the ground at a depth of d , in meters:

$$P_R = \frac{\omega^2}{8c^3 H_i \sigma_e} (JL)^2 e^{-d/\gamma}. \tag{7.3}$$

As is obvious from equation (7.3), as the antenna is set deeper, the radiated power drops exponentially. With f = 75 Hz and $\sigma = 1.6 \cdot 10^{-4}$ cm/m , the value of $\gamma = 4600$ m , and at a depth of 3200 m the radiated power is reduced only twofold, as compared with when the antenna is at the surface [21]. For an antenna array a cable made of an aluminum-magnesium alloy is used, with a cross section of 25 mm^2 [98]. Thus, the antenna cable can be buried at a considerable depth without substantial loss of power.

The ULF communications system of foreign fleets has high noise immunity. The key disadvantage of this system, in the opinion of foreign specialists, is the low rate of information transmission resulting from the very narrow pass-band of the receiver. For example, for the transmission of the "Fire Rockets" command when employing a five-digit code, with a radiated power of 130 W, r = 10,000 km , and a transmission rate of 0.03 bits/s, for this is required a t_{sv} of 20 min [21, 73, 90]. With a power of 3.88 MW, r = 10,000 km , and a transmission rate of 1 bit/s (band width, 27 Hz), from a group of 1024 standard messages it is possible to identify one message every 10 s [90]. Experiments abroad have demonstrated that it is possible to use this rate for transmitting a message when a submarine is sailing at depths of up to 80 m and at speeds of up to 13 knots, since atmospheric interference predominates in the towed receiving antenna. With deeper submersion of the submarine, it is necessary to reduce the rate of message transmission. Besides,

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with an increase in the submarine's speed, the signal-to-noise ratio is reduced, since the noise level of the antenna becomes comparable with the level of atmospheric interference.

In 1963 and 1972 experiments were made on ULF communications between the PDRTs in Wisconsin and nuclear submarines in the Atlantic Ocean. The results of calculations agree well with experimental data. At $f = 75$ Hz, with a radiated power of 0.96 W, a transmission rate of 0.03 bit/s and reception in the submarine ($h = 120$ m, $V = 6$ to 16 knots) with a towed antenna (spacing between spiral electrodes, 300 m), the communications range reached in 1963--$3.6 \cdot 10^3$ km, and in 1972--from $4.6 \cdot 10^3$ to $6.1 \cdot 10^3$ km [73, 90].

Considered another trend in the development and improvement of a system for VLF communications with submarines is the utilization of VLF radio relay equipment. As carriers of VLF radio relay equipment it is possible to use aircraft, ships and satellites, as well as mobile coastal radio relay equipment. For example, in the USA a miniature transmitter has been created which employs silicon controlled rectifiers with a total volume of 2.8 m^3, which is tenfold smaller than a transmitter of the same power operating on electron tubes. This transmitter operates in the 10 to 30 kHz band and has an output power of 150 kW and $\eta = 86$ percent [21].

For foreign aircraft radio relay equipment, VLF radio communications facilities are made in the form of special transceivers, modems, an antenna system and power supplies. In keeping with the Takamo program, aircraft VLF radio relay equipment has been developed with a power of 200 kW and a towed antenna, which has been installed on EC-130 and EC-135 type aircraft. Making up the equipment of the Takamo-3 system are HF transceivers, HF and MF receivers, microwave radio sets, microwave receivers, LF and VLF receivers and a VLF transmitter as the basic equipment. Storage devices make possible through relaying of messages or recording on magnetic tape for further relaying via any transmitter available on the aircraft, by radio telephone or radio telegraph (printing or Morse code). An antenna 8.0 to 8.5 m long is wound onto a drum and is unwound by means of hydraulic equipment. Vertical positioning of the towed antenna is made possible when the aircraft circles.

For the U.S. Navy a coastal VLF radio relay set has been developed which can be put in containers and is adapted for transporting on aircraft. These radio relay sets can be unwrapped on shore in a few hours. The antenna is 3 to 8 km long and is suspended on collapsible masts or is raised by a helicopter (on board ship, by the ship's helicopter).

For the purpose of improving the stability and reliability of VLF radio communications with submarines, promising, as is considered abroad, is the placement of VLF radio relay equipment on satellites.

In the submarine to shore direction, and important requirement for radio communications is secrecy. Transmission from submarines can be accomplished at any time of the day, by the acknowledgement method, with a frequent change of radio frequencies. Radio messages must be transmitted as infrequently and

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briefly as possible, as the result of which the possibility of the detection of submarines by radio reconnaissance and by antisubmarine forces is reduced considerably. For the purpose of improving the reliability of communications, reception on shore is arranged for at several points spaced at great distances, in order for conditions for the travel of radio waves to each reception point to be independent. All major marine theaters are equipped with several coastal communications units, and a submarine can transmit its message to any receiving point depending on which frequency it is best to use at a given moment. A special communications network has been set up between coastal units. The report received from a submarine is transmitted to the KP [command post] which controls this submarine.

As reported in many sources, for the achievement of high secrecy all transmissions from submarines are strictly regulated. It is recommended that transmitters be operated at reduced power with short signals without call letters. In addition, even since the time of the war for this purpose high-speed equipment has been used, which hampers radio direction finding and the interception of reports from submarines. Communication of submarines with one another and with surface vessels and aircraft is carried out by HF and microwave radio in the surface position or at periscope depth. Radio communication is carried out as a rule in individual radio networks.

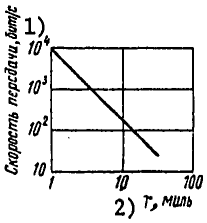

Figure 7.11. Approximate Curve for the Rate of Information Transmission Through a Hydroacoustic Channel Versus the Distance Between Correspondents

Key:
1. Transmission rate, bits/s 2. r, miles

Hydroacoustic facilities have great capabilities for communication of submarines with one another and with surface vessels. They are widely employed for communication with deepwater equipment. Abroad experiments are being conducted on maintaining communications between a submarine and aircraft by means of hydroacoustic radio buoys. GAS and various detonating devices are employed for hydroacoustic communications.

In arranging for hydroacoustic communications, it is taken into account that it makes possible only simplex communications and has a low level of secrecy

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and noise rejection and low carrying capacity for the communications channel, and the transmission rate must be slower, the greater the distance between correspondents (fig 7.11) [39].

Section Three

Automated Communications with Vessels and Ships

Chapter 8. Communications in Automated Systems for Controlling a Fleet

The increase in the number of craft and ships and in their speed and the intensity of traffic and improvement of the effectiveness of the fulfillment of plans by each vessel have necessitated the creation of new principles for controlling a fleet by employing automated control systems (ASU's).

The solution of the problem of improving control is especially important for marine transport, since here, unlike for industrial enterprises or associations, an important role is played by the dependence of production (the transportation process) on external conditions relating to the state of the freight market, which are hard to subject to confident forecasting, on the realization of supply contracts, and on hydrometeorological and other random factors. This set of circumstances necessitates the continuous renewal of information in a fleet ASU and timely reaction to it.

8.1. Role and Significance of Communications in a Fleet ASU

At the present time the "Morflot" automated control system is being created, in which the management of marine transport on the countrywide scale is being performed by the Ministry of the Maritime Fleet. The basic unit providing control of marine transport locally (in basins) is the maritime shipping line. Now 15 shipping lines are functioning in five marine basins [11].

Each shipping line has under its direct jurisdiction, in addition to a fleet, ports, shipbuilding yards, an operations force for emergency rescue and salvage operations, and other organizations.

An industrial automated system, the USSR MRKh OASU, is being created in the Ministry of the Fish Industry. This system represents a multi-profile and territorially distributed system entrusted with enabling the automation of the functions of planning, monitoring and reporting on, analyzing and managing the operations of industrial production at all levels of control. The OASU's upper control level is oriented toward enabling the automation of information processing at the industry's headquarters--the USSR MRKh. This level is supported by ASU's for basin central administrations, which in turn interact with ASU's for enterprises (ASUP's) and automated systems for control of the fleet in the field (ASUPF's).

All levels of the system obtain information from a single central source, which represents a group of integrated data processing systems (ISOD's)

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which make possible the gathering, required degree of consolidation and timely delivery as required of information on the performance of the ocean and coastal fleet, shore enterprises and the raw materials base of the global ocean and inland waterways. Information on the state of the raw materials base arrives at all levels of industrial control.

In the USA a global system for operations control of the armed forces (a GSOU) is being created. At the present time it includes 130 control agencies and is being employed for controlling naval forces. Information traffic between command stations is being conducted through the MO united communications system, which includes more than 80 countries in the world and has a total length of about 72 million channel-kilometers. Its main communications lines are the communications lines of "Autodyne" automated communications systems for transmitting digital information and "Autovon" for transmitting speech communications.

As an example of an automated system for controlling the ships of an operations force can be cited the American NTDS system [34]. The NTDS system is designed to enable the automation of the following processes:

The gathering, processing and reading out onto graphic display equipment of data on the situation, obtained both from ships and from external information sources.

The preparation of data, including the automation of calculations and the development of recommendations necessary for making decisions.

The transmission of decisions made to subordinate forces, including to ship, aircraft and other automated systems.

Similar systems have been developed for controlling naval aviation (the ATDS) and the marines (MTAKS).

Multi-level automated systems for controlling a fleet impose high requirements for reliability and fidelity in the transmission and receipt of information. In this connection, the need has arisen of creating new improved-reliability automated systems for communications between coastal control stations, and between control stations and vessels and ships and flagships (MRKh command vessels) and ships and vessels in the operations area being sailed in.

Fleet ASU's built with modern computers are able to process large information flows. Of course, the amount of information which must be gathered, processed and forwarded to destination points increases in proportion to the square of the industrial potential. For example, the new U.S. Navy telegraph communications unit in Arlington processes monthly up to 65,000 incoming and 15,000 outgoing messages, sending to its subscribers annually more than a million telegrams.

An ASU imposes high requirements on the speed of travel of information in communications systems. If new automated communications systems are supplied

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with a sufficient number of high-speed communications channels, then the exchange of information in an ASU will take place practically in real time. It will be possible to carry out a "conversation" with the ASU's computer at a distance and not only receive the text and diagrams on ships and vessels, but also quickly to make corrections and changes. Here labor productivity and the effectiveness of control will grow severalfold. The transmission of information in ASU communications channels must be accomplished in single numbers of minutes.

As the result of joint work by the MKKTT [International Telegraph and Telephone Consultative Committee], MEK [International Electrotechnical Commission] and MOS [International Organization for Standardization], the following requirements have been developed for systems for transmitting data to ASU's [45]:

In transmitting, it is recommended that transmission rates of 50, 75, 100, 200, 600, 1200, 1800, 3000, 3600 and 4800 bauds be employed, and, for broadband channels, rates which are multiples of 12,000 bauds.

The transmission of information must be made possible with an uncertainty factor of 10^{-5} to 10^{-7} for binary elements, and better (to 10^{-8} to 10^{-10}).

For the purpose of improving fidelity in communications channels, information feedback should be used.

For the transmission of information, it is recommended that the unified seven-element MKKTT/MOS code be used.

The majority of modern communications channels have been designed for the transmission of telegraph, telephone and television signals, without taking into account the requirements of ASU computers. It is possible to use existing communications networks for ASU purposes at the first stage by modernizing them and using rather complicated equipment.

The countrywide unified automated communications system (YeASS) will take into account the requirements of the USSR MMF and MRKh ASU's. In it provision is being made for the automation of communications processes in the transmission of information through non-switchable channels and systems for transmitting data through broadband channels. In addition, provision is being made for unification of the principles of message switching and data transmission equipment, including protection from errors, a primary code, etc. At the present time work is under way on the creation of automated communications between vessels and MMF and MRKh coastal radio centers, which should ensure the transmission of information with reliability and fidelity satisfying the requirements of a fleet ASU [48]. The existing marine radio communications system to a considerable extent satisfies the requirements of the existing system for controlling the maritime fleet, but does not satisfy the requirements of an ASU with respect to fidelity, carrying capacity and rate of information transmission.

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The automated system for communications between vessels and coastal radio stations, under development, is the main component of the "Morflot" ASU and the USSR MRKh OASU. It is designed for the transmission of information at a specified rate, fidelity and efficiency in control of the fleet and for ensuring safety in navigation for vessels.

The development and introduction of the new communications system for MMF and MRKh coastal radio centers are being performed on the basis of new promising methods and automated radio communications facilities employing a satellite communications system and modernized and new radio centers.

Table 8.1.

Kinds of transmission, channels and communications systems	Year	Carrying capacity, bits/s
Telegraph sending (Gauss equipment)	1834	1-2
Morse code telegraph sending (record on tape)	1844	4-5
Morse printing telegraph systems	1850	15
Baudot multiple telegraphy (16 units in a single line)	1874	100
First telephone lines	1890-1900	$1.2 \cdot 10^3$
High-frequency telegraphy with a carrier (12 channels)	1918	$1.2 \cdot 10^4$
Coaxial cable (600 TLF [telephony] channels)	1945	$1.05 \cdot 10^5$
Microwave RR [manually controlled] communications lines (1800 telephone channels)	1955	$1.3 \cdot 10^6$
Modern networks employing coaxial cables and microwave communications lines (32,000 channels)	1965	$1.3 \cdot 10^7$
Planned helical waveguides (10,000 TLF channels)	1975-1980	$1.15 \cdot 10^8$
Satellite communications systems	1975-1977	$1.3 \cdot 10^8$
Laser communications systems	1985	$1 \cdot 10^{11}$

ASU's require an increase in the carrying capacity of communications channels. The carrying capacity of different channels is shown in table 8.1. It is obvious from this table that the carrying capacity of communications channels has been increasing exponentially. State and inter-State communications lines of promise for ASU's of the future will be constructed by employing waveguide, satellite and laser communications channels. The amount of information which can be sent through a specific communications channel is proportional to the width of the passband or to the frequency range assigned for communications. In order to increase the carrying capacity of a channel it is necessary to increase the frequency range (cf. table 8.1).

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8.2. Fundamental Principles of the Design of a Fleet ASU Communications System

The practical implementation and simultaneous entry into service of a great number of industrial ASU's in the country are possible only after the solution of the problem of organizing the exchange of information between the subjects of these automated systems, including the fleet ASU and the MRKh OASU. Up to the present time, within the framework of each ASU usually created has been its own narrowly specialized information traffic subsystem. The structure of this information system has as a rule imitated the control structure used in the ASU [34, 36]. This has resulted in the fact that the communications channels of this information network (IS) have been used only in the interests of a specific system of gathering and processing information.

The information network of the Statewide system for gathering and processing information should be constructed on the basis of unified specialized centers for the distribution (commutation) of information flows between different ASU's. Generally, these centers must not be elements of any single ASU. It is advisable to distribute them according to the territory principle, taking into account the requirements of different ASU's.

The idea of the total automation of communications processes in an ASU by means of equipment employing a program for the control of information flows stored in a special communications computer originated here and in other countries in the very first stages in the development of computer technology.

In 1963, in the USA was created the USA DCS MO automated communications system, consisting of two separate automated communications networks: "Autovon" and "Autodyne." Later these automated communications networks were united into a single communications system, the "Unicom," used in the interests of controlling the U.S. Navy [4, 34, 104].

The basis of automated communications systems are automated commutation centers, to which are connected both users and ASU trunk communications lines.

Special automated centers for the commutation of information flows are divided into two types: channel switching centers (TsKK's) and message switching centers (TsKS's).

Channel switching centers accomplish the delivery and distribution of information by automatically connecting incoming and outgoing communications channels. A TsKK enables the automatic reception and storage of information until the moment a channel is free on the route required, and then establishes automatic transmission to the addressee. With manual operation, the operator transfers it to the appropriate outgoing equipment.

Message switching centers enable the automatic distribution of information in the communications unit to the local and remote users served. In message switching there is no direct connection between incoming and outgoing communications channels, as occurs in TsKK's.

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Let us discuss through an example one of the possible variants for equipping ASU units with communications equipment, as applied to a fleet (fig 8.1). Shown also in the diagram in fig 8.1 is the nature of the communications channels connecting ASU units via TsKS's and UATS's [agency automatic telephone exchanges] (GATS's [city automatic telephone exchanges]).

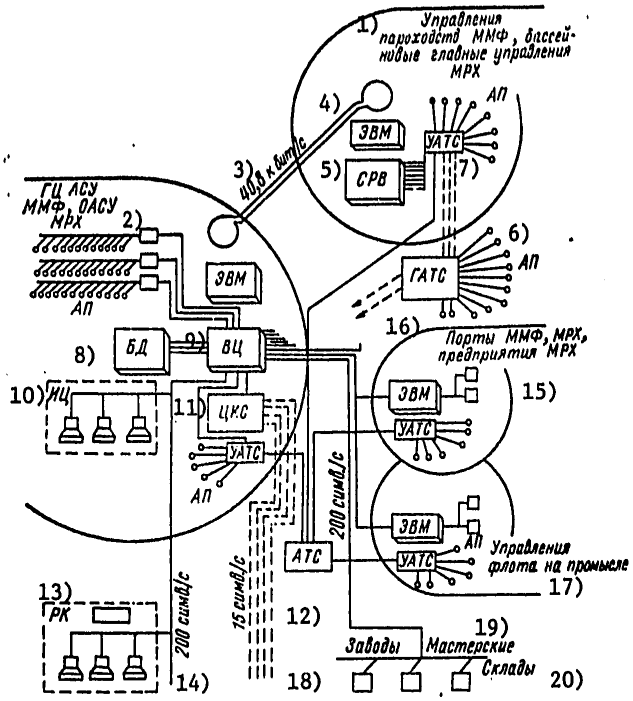

Figure 8.1. Structural Diagram of Distribution of Communications Equipment in Fleet ASU Units (Variant)

Key:

1. MMF shipping line administrations; MRKh basin central administrations
2. MMF ASU GTs [main center]; MRKh OASU
3. 40.8 kbits/s
4. Computer
5. SRV [time-sharing system]
6. AP [user console]
7. UATS
8. BD [data bank]
9. VTs [computing center]
10. ITs [information center]
11. TsKS
12. ATS [automatic telephone exchange
13. RK [command register]

[Key continued on following page]

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14. 200 characters/s
15. MMF and MRKh ports; MRKh enterprises
16. GATS
17. Control of fleet in the field
18. Plants
19. Workshops
20. Warehouses

The functions of the elements of such an automated control system can be represented in the following manner, by analogy with [35]: The USSR MMF and MRKh ASU main center is equipped with large-capacity computing centers (VTs's) for processing data with a stored data bank (BD), enabling an organized collection in a memory of different data required by management and ASU users. MMF shipping line administrations, MRKh basin central administrations and fleet headquarters have large computing centers operating in the time-sharing (RV) mode for processing routine information. Ports, bases, large enterprises of the fleet, and the like, are furnished with medium-size computers with punched cards, which are used for daily routine work. When solving problems requiring fairly rapid reaction of the system and processing of a large amount of information, these small computers are connected through communications channels with the large one, and the printers of the small computer are used.

Small enterprises, warehouses, and the like, can be furnished with punched card readers with average speed of response and with printers connected through telephone channels with a carrying capacity of 200 characters per second to the main computer, which performs the entire job of data processing for these enterprises. Among users of all ASU ranks are installed user sets (AK's), equipped with appropriate consoles making it possible to obtain the appropriate information from their own and the main ASU computer. User consoles (AP's) located in the area of the central point of the ASU are connected to the computer through telephone channels via an ATS. Similarly, other users connected to the ATS (UATS) can be linked with this computer.

Communications can be established with outside correspondents through a dial telephone network or through a data transmission network at a rate of 100 to 200 bauds via a TsKS, or through a subscription telegraph (AT) network or a "Telex" network, at a rate of 50 bauds. In the "Telex" system each user has an individual subscriber's line and number; the subscriber's start-stop printer is equipped with a dial similar to a telephone dial, by means of which he can call another subscriber. Computers can be connected to the network. Subscribers using the "Telex" system can establish international communications with subscribers in other countries. In the USA there is a teletype data transmission network (TWX), enabling transmission at a rate of 150 bits/s. TWX system lines can be connected to lines of the "Telex" system.

8.3. Communications Channels in a Fleet ASU

In fleet ASU automated communications systems, for communications between coastal control units underground cables are used, as well as underwater coaxial cables and radio relay and tropospheric communications lines, and for

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communications with vessels at sea, microwave, HF and MF radio communications lines. With the development of satellite systems, this form of communications has become widespread for carrying out communications with vessels on intercontinental routes at great distances from their bases, and between vessels. These communications channels enable global communications.

Underground and Underwater Cable Communications Lines

These communications lines have turned out to be the most developed and most ready for use in ASU automated communications systems. They have become widespread in continental areas of the globe (especially in Europe and North America), as well as between continents.

The frequency band for underwater cable lines, according to MKKTT standards, should be 0.3 to 3.4 kHz. This band ensures 90-percent syllabic intelligibility and better than 99-percent intelligibility of phrases. For 100-percent syllabic intelligibility a band to 5000 Hz is required, which unjustifiably makes communications expensive. The permissible lag time has been set at 60 ms for the lower frequency of a signal, and at 30 ms for the higher.

For marine trunk cable communications lines of great length, a frequency band of 0.2 to 3.05 kHz has been selected. This makes it possible to accommodate in a cable frequency band of 60 to 108 kHz 16 TT [carrier telegraphy] channels instead of 12 with a standard of 0.3 to 3.4 kHz. The number of tone frequency channels in underground cables is from 300 to 2700, and from 24 to 128 in underwater cables. In England an underwater cable system has been developed for 10,800 channels in the band up to 60 MHz.

Radio Relay Communications Lines

In recent years in ASU communications lines between coastal units the communications network has been expanded because of the construction of radio relay communications lines. These lines are used especially where economic, utilization and topographic conditions for them are more favorable, as compared with laying underground and underwater communications lines. Radio relay communications equipment has found application in international communications lines and satisfies the high requirements of the MKKR and MKTT, and, consequently, ASU requirements. Broadband radio relay systems are used in international communications lines. The carrying capacity of these systems is from 300 to 1800 telephone channels with an 0.3 to 3.4 kHz band. At the present time in the development stage are radio relay communications lines for 2700 telephone channels. Radio relay stations with a medium and low carrying capacity (for 300 telephone channels and less) are used in regional ASU networks. Usually all radio relay lines operate within the range of direct visibility between antennas at the same interval of approximately 50 km. If topographic conditions and heights for antenna placement allow, then this distance can be increased to 150 km, and with long-range tropospheric propagation, to 400 km and more. In operation in the SHF band, depending on the relief of the terrain, the height of masts reaches 20 to 60 m.

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Radio relay communications lines, with the existence of 100-percent redundancy and provision for automatic connection of the standby channel, satisfy ASU requirements with respect to the reliability of these communications channels.

MF and HF Band Radio Channels

At the present time, in the fleet ASU radio communications is the only means of exchanging information with vessels at sea. In the traffic control system for maritime vessels HF radio communications facilities make it possible to ensure the timely transmission and reception of information regarding the location of vessels and their operating and production activities, and also the rapid conveyance to vessels of management decisions. By radio vessels are warned about a change in meteorological and navigating conditions. Radio communications are of special importance for the transmission of alert and distress signals, as well as for the timely taking of measures for rendering assistance to vessels. It is characteristic that according to some sources [35] shortwave communications is identified with ship communication lines. The number of long-range HF radio lines with vessels has been steadily increasing and has reached 50 percent of the total number of channels. The major radio traffic load is transmitted through them. Printing, facsimile telegraphy, data transmission and single-sideband radio telephone communications are extensively used on HF lines for communications with vessels. A disadvantage of HF radio lines is the great dependence of the range and fidelity of communications on the state of the ionosphere and other factors discussed in detail in chap 2. HF channels to a certain extent limit the transmission rates needed for the effective employment of ASU's. With a 250 Hz passband the transmission rate is nominally 100 bauds (maximum of 200 bauds), and with a 500 Hz passband, 200 and 400 bauds, respectively. In the HF band, with a transmission rate greater than 200 bauds perceptible phase distortion appears. With double-sideband HF radio communications lines it is possible to transmit information with good fidelity in 120 telegraph channels.

The zone principle of communications is employed for the purpose of improving the fidelity, efficiency and reliability of transmission through marine HF communications channels. A coastal radio center makes possible long-range two-way communications for vessels located in a specific area of the global ocean assigned to this radio center. The operating zones for coastal radio centers or coastal communications units (US's) can be calculated with a computer [48]. Of course, the characteristics of HF radio communications are worsened considerably in latitudinal communications lines of great length (two or more discontinuities). These characteristics can be improved by setting up coastal or marine radio relaying points installed at distances of 2500 to 3000 km from one another (one discontinuity). The employment of vertical or back-slant probing improves the reliability of communications in these radio lines.

The problem of improving the noise-rejection of a prospective system for marine radio communications in the HF band involves the problem of combating pulsed interference. Tests on routes 7000 to 8000 km long have demonstrated that the relative phase telegraphy (OFT) mode enables higher noise rejection

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than the frequency-shift telegraphy (ChT) mode [48]. With the existence of signal fading, one of the main methods of improving the noise rejection of marine printing channels is reception of the same information while separating channels in space (100 m and more) or by frequency (500 Hz and more). With the frequency diversity method a single multi-channel receiver is required, and for dual reception with the space diversity method, two receivers.

Good results in operating through HF communications channels are produced by audio frequency telegraphy (TT) equipment with OFT. A typical example of a multi-channel TT unit employing OFT designed for operation in HF radio channels is the "Kinepleks" unit. In it are employed 20 carrier frequencies, at each of which, by means of double relative phase telegraphy (DOFT), are formed two telegraph channels (a total of 40 channels). Transmission of these 40 channels is carried out in a single-band telephone channel with an 0.3 to 3.0 kHz band. The great number of telegraph channels makes it possible to increase the carrying capacity of the telephone channel or to transmit the same telegraph information in several frequency-diverse channels, thereby improving the noise rejection of a printing line in an ASU system.

An effective means of combating interference is the utilization in HF radio lines of correction codes making it possible to detect and correct errors in ASU APD [data transmission unit] combinations used.

Satellite Communications Channels in a Fleet ASU

A Soviet artificial Earth satellite, the first in the world, was launched into orbit around Earth on 4 October 1957. This has made it possible to predict, and then accomplish, global radio communications via artificial Earth satellites. This form of communications is promising in the MMF and MRKh ASU for communications with vessels sailing great distances from their bases. The calculation of satellite communications lines is described in chap 2. Here are discussed questions relating to the prospects for employing them in a fleet ASU.

The greatest development has been given to satellite communications systems (SSS's) employing active radio relaying, which is especially important for ASU's. Three satellites revolving synchronously in the equatorial plane around Earth at an altitude of 36,000 km make it possible to realize global radio communications (except for areas near the poles) in an ASU at speeds close to real time.

If the reliability of communications must be not less than 99 percent, then there must be one satellite in the zone of visibility of a system with orbit correction, and four or five or more satellites in a system with uncontrolled satellites. But a communications system with uncontrolled satellites is dependent to a lesser degree on the failure of individual ISZ's [satellites]. Global SSS's must take into account the areas in which vessels sail, as well as the need of fleets for telephone and multi-channel telegraph printing and data transmission channels for the fleet ASU. Here the speed and fidelity of information transmission must not be worse than through the cable and

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radio relay lines used in the ASU. It must be mentioned that the number of channels in SSS communications groups can be selected many times higher than the standards set by the MKKR for cable and RRL [radio relay line] communications lines. For non-stationary SSS's it is necessary to take into account the Doppler effect, which results in a shift in communications frequencies. According to the standards, the maximum frequency difference must not be greater than $\pm$ 2 Hz [47]. Compensation of the Doppler effect does not present difficulties even with heavily prolate orbits. An experiment in the employment of SSS's has demonstrated that communications via several satellites in orbits not higher than 14,000 km will be within permissible limits with respect to lag time. For SSS's the frequency range of 0.1 to 10 GHz is used.

In the USSR in 1965 was created a national SSS using "Molniya-1" and "Molniya-2" satellites. This system has been employed at its first stage primarily for the transmission of television signals of the "Orbita" system for the territory of the USSR and in the "Intervideniya" network. The telephone communications channels of this SSS are employed on long routes, including for USSR Academy of Sciences ships. At the present time it is being employed extensively for USSR long-range radio telephone and telegraph communications. Land stations set up in Eastern Europe, France and Cuba make possible USSR long-range communications by means of "Molniya" communications satellites [47, 48]. On 22 December 1975 a communications system began to function via a "Raduga" satellite, enabling round-the-clock telephone communications.

Satellite communications systems abroad began to be developed practically in 1965 [47]. By the beginning of 1972 the "Intelsat" consortium had accomplished intercontinental communications via several "Intelsat-3" and "Intelsat-4" communications satellites. The "Intelsat-4" satellite will surpass its predecessor sevenfold with regard to channel capacity. The number of telephone channels of the "Intelsat-5" satellite will be increased to 10,000, and the satellite's service life to 10 years. In 1978 the number of telephone channels in satellites equals 420,000 [35].

With simplification of channel-forming terminal equipment and antenna systems, the extensive employment of SSS's in an ASU for communications with the vessels of a fleet is possible. A solution to the problem of multi-station access (MSD) will promote the introduction of SSS's on vessels. The essence of MSD consists in the fact that communications is carried out via different SSS radio relay units and a single radio relay unit, not by a single pair of SSS stations, but by several pairs of land and marine stations located in the range of visibility of the satellite at different geographic points.

The international consultative organization (IMKO) is at work on creating the INMARSAT marine SSS. The USSR is included in the number of countries taking part in the INMARSAT SSS. The entry into service of the first phase of this system is planned for 1978-1979. The lifetime of the satellite is on the order of seven years. Four satellites are planned for the first stage: two over the Atlantic (one standby) and one each over the Pacific and Indian oceans. The standby satellite can be transferred in a brief time to the area

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of the Pacific or Indian oceans in case one of the satellites in this area goes out of order [47].

The quality of transmission will satisfy ASU requirements (probability of error per bit equal to 10^{-5}).

Chapter 9. Automated Communications Facilities for a Fleet ASU

The key component communications processes as applied to a fleet ASU are the reception and transmission of information in vessel to coastal radio center and coastal radio center to vessel sections and between coastal radio centers of zone communications units and ASU control points. In modern ASU's the exchange of information through coastal communications channels is accomplished via channel switching centers and message switching centers.

9.1. Automation of Communications Processes; Message Switching Centers (TsKS's)

The organization of information traffic in networks with message switching involves the formalization of messages entered into the communications network, optimization of the lengths of messages, selection of procedures for finding routes for transmission via a TsKS while constructing algorithms for information traffic in the ASU in question, and other problems. The distinctive features of networks with TsKS's consist in the fact that they do not make it possible to realize the connection of channels in real time with actualization of the effect of direct and immediate serving of users. However, in modern networks with TsKS's the total delays of messages in TsKS's and in circuits amount to single numbers or dozens of milliseconds; therefore, even in voice conversations these delays will be practically unnoticed [36]. For the realization of such small delays high-speed circuits for communication between TsKS's are employed, in which are used high-output computers. In addition, these TsKS computers operate as time-sharing systems (SRV's). They have several programs making it possible for a number of users to have access to them simultaneously, with a delay not longer than 1 to 3 s [35].

A communications information network (IS) utilizing switching centers is illustrated in fig 9.1. Formalized messages in an IS with TsKS's have headings at the beginning of each coded message and then follows the text of the message, which ends with a symbol for the end of the coded message. The choice of the method of addressing is an important fundamental problem.

One possible heading format is shown in fig 9.2 [34]. All commands in the heading are united into seven functional groups. The heading ensures accuracy of addressing, priority and a routine. Coding of tags is performed with two-element code No 5 (GOST [All-Union State Standard] 13052-67), adopted in the USSR. With the zonal distribution of TsKS's, for a multi-level communications network with a radial-junction structure, optimal is the method of addressing whereby the user's address indicates all intermediate switching stages and has the form [36]:

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$$a_{i1}a_{i2}, \ldots, a_{ik} \qquad (9.1)$$

where a_{ij} is the number of a unit with a TsKS with a stage matching the i-th user; and k is the number of network stages.

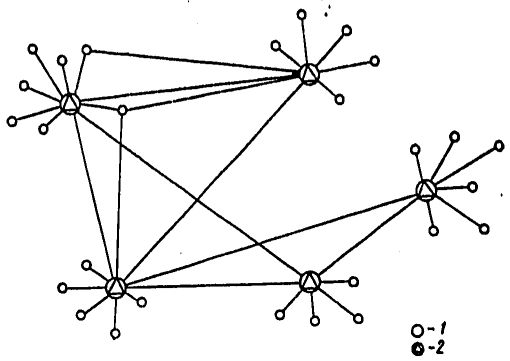

Figure 9.1. Communications Information Network Employing Switching Centers: 1--IS users-unit; 2--switching centers

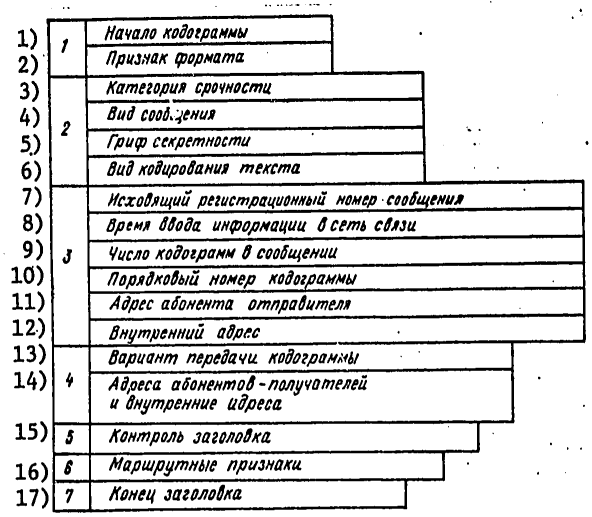

Figure 9.2. Message Heading Format in Automated ASU Communications (Variant)

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Key:

1. Beginning of Coded message
2. Format tag
3. Category of urgency
4. Type of message
5. Security classification
6. Form of text coding
7. Outgoing radio relay number of message
8. Time of entry of information into communications network
9. Number of coded messages in communication
10. Serial number of coded message
11. Address of sender-user
12. Internal address
13. Variant for transmitting coded message
14. Address of receiver-users and internal addresses
15. Heading check
16. Routing tags
17. End of heading

A communications information network with TsKS's should have high ratings for reliability and probability-vs.-time information traffic characteristics, as indicated in chap 8. It has equipment for automatically monitoring the state of communications channels and the degree of loading of TsKS computer memories.

The productivity, ρ_{ij}, of an IS with TsKS's is generally determined by the speed of response and volume of the memory of TsKS hardware used for converting a transmission and improving its fidelity and for controlling the flow of information into the IS. If the TsKS hardware does not impose limitations on the productivity of the circuits connected to it, then it can be considered that

$$\rho_{ij} \geqslant \sum_{\substack{k,\ l=i \\ l,\ k=j}} \rho_{kl}. \tag{9.2}$$

Otherwise,

$$\rho_{ij} = \sum_{\substack{k,\ l=i \\ l,\ k=j}} \beta_{k,\ l}\, \rho_{kl}, \tag{9.3}$$

where $\beta_{k,\ell}$ are certain factors taking into account limitations from hardware, which are generally different for different data transmission circuits of a specific TsKS, a_i.

Indicators of the reliability of IS elements, determining the reliability of circuits and hardware of units with TsKS's, can be presented in the form of a table of distributions, $P\{T_{ij} \leq X\}$ and $P\{\tau_{ij} \leq X\}$, where T_{ij} is the time of failure-free operation, and parameter τ_{ij} is the time for the recovery of the data transmission circuit, b_{ij}, as a whole. The indicators

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of the reliability of an IS with TsKS's are functions of the respective individual parameters T_{ij} and τ_{ij} of the k-th operating channel in the structure of channel b_{ij}, as well as functions of the time for switching a_{ij} and of the standby discipline, ψ_{ij}, on route b_{ij}. In other words, T_{ij} and τ_{ij} can be represented in the form [34]:

$$\left.\begin{aligned} T_{ij} &= f\left[T_{ij}^{(k)}, \tau_{ij}^{(k)}, \bar{a}_{ij}, \psi_{ij}\right], \ \overline{k=1; s+r;} \\ \tau_{ij} &= \varphi\left[T_{ij}^{(k)}, \tau_{ij}^{(k)}, a_{ij}, \bar{\psi}_{ij}\right], \ \overline{k=1; s+r,} \end{aligned}\right\} \qquad (9.4)$$

where s is the number of operating channels and r is the number of standby communications channels in circuit b_{ij}.

Indicators of information delays in elements of an IS with TsKS are determined by the respective distributions, $P\{t_{ij} \leq X\}$, of the servicing time, t_{ii}, in the hardware of TsKS's in the IS and distributions, $P\{t_{ij} \leq X\}$, of the time for transmitting information in data transmission circuits, b_{ij}.

The distribution of parameter t_{ii} depends on many factors, and primarily on the structure of the IS, the volumes of information flows circulating in the network, and the productivity of data transmission circuits and TsKS hardware. A variant of the structural diagram for the distribution of TsKS hardware is shown in fig 9.3 [36]. A TsKS contains three groups of hardware:

A combination of secondary channel-forming equipment consisting of modems, performing modulation and demodulation and enabling unified joining of channels and terminal equipment at speeds of from 200 to 4800 bits/s and higher.

A grouped combination of equipment for information exchange consisting of several information traffic processors (computers) (POI's). Used fairly extensively in practice is the connection of three processors functioning in parallel according to a "Triplex" arrangement, where the results of information processing in each of the three POI's are tested according to the majority principle. Modems and telegraph channels are connected to a grouped combination of POI's via a special unit which switches all modems and telegraph channels to a single master POI or reproduces and switches this information over to all POI's. In the reverse direction signals are always sent out only from the single master POI. A distinctive feature of the problems solved by a TsKS POI is their stability over time, unlike the constantly varying problems entrusted to a general-purpose computer.

The grouped message switching complex includes several message switching processors (PKS's). A PKS is distinguished from a POI by its high complexity, and by the diversity, dynamics and volume of problems solved. The structure of a PKS differs little from the structure of general-purpose computers. The volume of the memory of the working storage, the OZU, and of the permanent storage, the DZU, enables the formation and storage of a great amount of

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AT SEA

BY V. I. SOLOV'YEV, L. I. NOVIK AND I. D. MOROZOV

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information of various urgency categories. For the purpose of ensuring reliability requirements, the OZU can be controlled from two directions--from the main and standby PKS. The DZU is usually used for storing software for constants and functional tables.

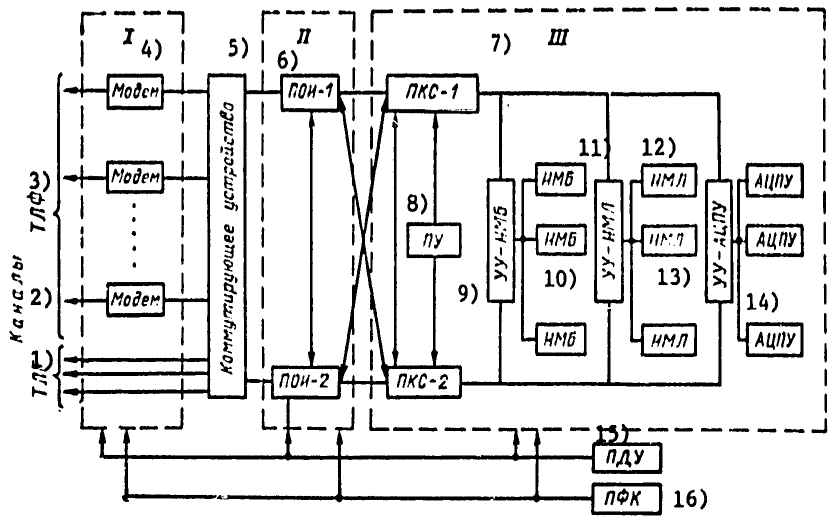

Figure 9.3. Structural Diagram of Distribution of TsKS Equipment (Variant): I--complex of secondary channel-forming equipment; II--grouped information traffic complex; III--grouped message switching complex

Key:

1. TLG [telegraphy]
2. Channels
3. TLF [telephony]
4. Modem
5. Commutating unit
6. POI-1
7. PKS-1
8. PU [peripherals]
9. UU-NMB [magnetic drum storage control unit]
10. NMB [magnetic drum storage]
11. UU-NML [magnetic tape storage control unit]
12. NML [magnetic tape storage]
13. UU-ATsPU [alphanumeric printer control unit]
14. AtsPU [alphanumeric printer]
15. PDU [remote control console]
16. PFK [channel-forming console]

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Messages to the TsKS enter the OZU's magnetic drum storage (NMB). Almost all messages are recorded simultaneously either in the magnetic tape storage (NML), or they are printed out. At the desire of the TsKS operator, the contents in the NML are read out onto the alphanumeric printer (ATsPU). Electrical and algorithmic links between external equipment (NMB, NML and ATsPU) and the TsKS are accomplished via appropriate control units (the UU-NMB, UU-NML and UU-ATsPU). In place of these it is possible to use a single general-purpose (group) control unit.

The TsKS's control console (PU) is designed for controlling the operating modes of the TsKS from several PKS's and simultaneously serves as a means of contact between the TsKS operator and these PKS's. The control console is equipped with an electrically controlled typewriter (EUPM), a tape puncher (PL) and also a special keyboard for access to the computer. The DS-4 system variant of the arrangement of technological equipment for a TsKS is discussed in [4].

An analysis of different variants of the design of a TsKS [33, 34, etc.] shows that they perform the following key functions:

Character-by-character reception of information in communications channels of different types hooked up to the TsKS.

Formation (storage) from characters (symbols) received of blocks of a specific length (usually from five to eight).

Priority input of information into the traffic processor or directly into the central processor of the TsKS (the UK).

Analysis of characters received for the purpose of determining the beginning of a line block for each of the channels served, and the realization of group and cyclic information.

Decoding of information in keeping with the rules for the structure of a redundancy code and the formation of line blocks in the form of which a message is transmitted through the communications channels of data transmission circuits.

The detection of service tags of the "start" and "end" type for a coded message of a communication and the formation by their means, from blocks received, of finished communications or coded messages whose length usually is greater than the length of blocks.

The entry of coded messages (communications) formed into the TsKS's computer memory, and the organization from them of a priority sequence of messages for attending to.

Priority attention to messages as a function of type and urgency category.

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Selection for each message of the optimal route, at the moment of time in question, or combination of routes for transmission, based on network information on the state and load of communications network channels.

The organization of periodic exchange of network information with other TsKS's (UK's) for the purpose of constantly renewing information on the state and load of channels.

Monitoring of the state and load of internal communications channels of the TsKS in question.

Automatic confirmation of the receipt of messages.

Ensurance of the preservation and further transmission of messages with temporary overloading of the TsKS.

The recording and documentation of messages passing through the TsKS or of service tags contained in them.

The recording of all messages whose transmission via the TsKS in question is difficult or impossible, as well as of messages in which errors have been detected.

The organization of procedures for the transmission of conference and multi-address communications, as well as for transmission by lists.

The output of communications (coded messages) into communications channels, with their prior breakdown into line blocks and their coding in conformity with the rules of the code employed.

Symbol-by-symbol entry of line blocks into communications channels.

The ITT firm (USA) has developed TsKS's which employ two special-purpose computers. One of them is in the working state and the other in the standby state. The TsKS's are linked together by communications lines of the "Autodyne" system. The TsKS of the ASU for strategic forces has main and standby communications channels. In these TsKS's are provided 32 duplex communications channels and 80 to 90 simplex channels. The communications system has an extensively ramified network and multiple duplication of communications channels [34].

In "Autodyne" systems TsKK's serve the most important users. The TsKS's of the "Autodyne" system are interlinked by trunk telephone lines and carry out information traffic at a rate of from 2400 to 4800 bauds. In 1968 24 million punched cards were sent per 24-hour period through the "Autodyne" system. Employed in information traffic are two main communications formats: the data format and the teletype format. Six urgency categories are provided for in the "Autodyne" system: prompt, alert, immediate, first-priority, ordinary and not urgent. The transmission time for these urgency categories

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is within the range of 3 to 20 min. This time standard has been calculated on the basis of the average length of a communication on 15 to 20 punched cards or 15 to 200 words for a teletype communication (a word of five characters).

In the transmission of reports, five levels of secrecy have been established: top secret, secret, for official use, classified only in transmission, and not classified. The measures used in the system to monitor the parameters of channels and equipment make it possible to discover not more than a single error in 10 million characters. In the 465-L automated communications system the probability of the occurrence of an error is even less--10^{-10}. The required fidelity has been achieved by employing the ASC11 code [35].

At the end of the 60's the U.S. Department of Defense embarked on the implementation of a project for creating one of the largest automated global communications networks, the "Arpa." By 1973 it included 26 computing centers. Information traffic between centers is carried out through cable and satellite communications lines. Because of the high rate of message transmission in this information network, the time for a response to a computer user's interrogation does not exceed 2 s. In this system are employed TsKS's enabling the setup and monitoring of a channel [34].

9.2. Data Transmission Equipment and Its Parameters

Modern automated data transmission systems designed on the principles of automated switching centers (TsKS's) represent a complex of communications facilities which include the following in addition to TsKS's and communications channels: data transmission equipment (APD); input-output units enabling the matching of channels with computers; and equipment for monitoring the working order of communications channels and channel-forming equipment.

Depending on the type of channels used, APD is divided into low-speed, with 50- to 100-baud telegraph channels, medium-speed, using 200- to 4800-baud telephone channels, and high-speed, employing broadband channels (12,000 bauds and more).

Data transmission equipment includes a group of devices for converting signals, units for protection from errors, and auxiliary units, e.g., automatic call and response units [79]. In addition, it contains individual units for improving fidelity.

Signal converting equipment (UPS) makes possible the back and forth conversion of data signals in a form suitable for transmission through a communications channel. UPS is divided into equipment operating through telephone (modems) and telegraph channels.

Modems (a modulator and demodulator united in a single unit) represent a functionally and structurally independent component of APD. The choice of the modulation method and type of receiver in a modem depends on the characteristics of the communications channel. A modem together with the

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communications channel determines the data transmission rate. The characteristics of some modems are given in table 9.1.

Table 9.1.

1) Тип модема	2) Шифр	3) Канал и дальность связи	4) Способ передачи	5) Скорость передачи, бит/с	6) Вид модуляции	7) Габариты, мм	8) Масса, кг
9) ТАМ-200	10) ЕС-8002	11) Коммутируемые и некоммутируемые каналы	14) Дуплексный, симплексный	16) до 200	20) Частичная	169×400×280	11
ТАМ-201	ЕС-8002	То же 12)	То же 15)	до 300	—	169×400×280	10
ТАМ-600	ЕС-8006	»	Полудуплексный или симплексный	до 600 до 1200 17)	—	169×400×280	11
ТАМ-601	ЕС-8006	»	То же	600 или 1200	—	169×400×280	10
Модем 2400	ЕС-8010	»	»	18) 2400 и обратн. 75	21) Фазовая	169×400×280	10
	ЕС-8011	13) до 13,9 тыс. км		19)			
Модем 4800	ЕС-8015	То же	»	2400 или 4800 обратн. 75		169×400×280	10

Key:

1. Type of modem
2. Code
3. Channel and communications range
4. Method of transmission
5. Transmission rate, bits/s
6. Type of modulation
7. Overall dimension, mm
8. Weight, kg
9. TAM-200
10. YeS-8002
11. Switched and unswitched channels
12. Ditto
13. Up to 13,900 km
14. Duplex, simplex
15. Semiduplex or simplex
16. Up to 200
17. 600 or 1200
18. 2400 and 75 back
19. 2400 or 4800, 75 back
20. Partial
21. Phase

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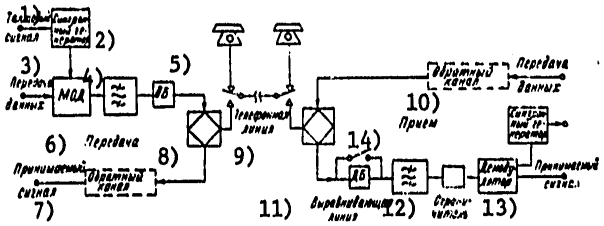

Figure 9.4. Functional Diagram of YeS-8006 (AM-1200) Type Modem. Circuits indicated with a dotted line are used only in the duplex variant.

Key:

1. Clock signal
2. Synchronous generator
3. Data transmission
4. MOD [modulator]
5. dB [as published]
6. Transmission
7. Received signal
8. Return channel
9. Telephone line
10. Reception
11. Balancing line
12. Clipper
13. Demodulator
14. DB [differential unit]

A functional diagram of a type YeS-8006 (AM-1200) modem when operating in the semiduplex and duplex modes is shown in fig 9.4. Binary information signals enter the 600/1200-baud modulator and are converted into a double frequency telegraphy (DChT) signal. The modulator ensures the absence of a sudden change in the phase of the output signal with a change in frequency ensuing under the influence of the modulating signal. The frequency modulated signal enters a filter with a stretcher. The modem's output signal enters the telephone line via the differential system of the line termination unit. The return channel modulator, enabling the transmission of monitoring signals for the quality of the transmission of data, is designed similarly. Signals arriving from a line belonging to another user are fed to the input of the receiver's filter via the line termination unit and a line stretcher. The filter admits signals whose range falls within the filter's frequency band. A clipper amplifier converts input signals into square-wave pulses with constant amplitude. If the signal level under the influence of noise is lower than the detection level, then an interrogation signal passes through the return channel for the repetition of its reception. With a normal level, signals are converted by the demodulator into binary information pulses.

The group delay time corrector and amplitude corrector (line balancing unit) serve the purpose of improving reception conditions and can be built into the data transmission line by employing modems. Synchronous operation of

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the modem is made possible by clock and synchronous generators, which form a separate unit. The equipment of the YeS-8015 modem includes the following: a data modem, a return channel modem, a connecting line phase-frequency characteristic corrector, a corrector tuning system, an internal monitoring circuit, a remote control unit, a power supply and a conversation-and-call unit.

It is possible to connect to modems any data processing terminal units, devices for protection from errors, concentrators, etc., which satisfy the MKKTT recommendations and the speed called for in the modem in question.

With a small number of lines and a not too considerable volume of information it is possible to implement APD without modems, as has been done in model 8050 APD [35]. In this equipment, transmission from punched paper tape is accomplished through a telephone line via a dial telephone set on which the addressee's number is dialed. A special modem is not needed here, since the unit is connected acoustically to an ordinary telephone and the information is transmitted in the form of sound signals. The transmission rate when using five-channel paper tape is 43 characters per second, and 30 characters per second with eight-channel tape.

Telegraph signal conversion units are a necessary component of a remote data processing system operating in a telegraph communications network. They are connected to low-speed user stations and make possible the duplex transmission of synchronous and asynchronous data signals at a rate of up to 200 bits/s. The TTV-200 type unit converts sequential binary data signals into double-band telegraph signals. In the reception of data the process takes place in reverse order. The TTKh-20 type unit is connected to switchable channels with double-band transmission. This unit can have a number dial or a telegraph set keyboard.

Error protection devices (UZO's) make possible reduction of the influence of distortion originating in data transmission. In the design respect, in these devices the principles employed in the design of computers are used. In large TsKS's the functions of UZO's can be transferred to computers. Among users, the receiving and transmitting halves of the UZO are located on a single rack. APD of the "Akkord-1200PP" type having UZO's include the following: a data transceiver, an operator's desk, a PVK [punchcard computer complex] unit or telephone set, a PL-150 tape puncher, and an FS-1501 facsimile reader.

The input and output of data are performed by means of electromechanical devices employing as a data medium punched paper tape 17.5 and 25.4 mm wide. This APD makes it possible to arrange for the transmission and reception of information from units for linking with a computer or from data processing equipment.

Let us consider as an example the TOR (ARQ) APD. It operates in single-channel HF radio telephone communications lines according to the simplex principle, with erasure. This is a synchronous system with a seven-element binary code, with 3/4 parity check. A structural diagram of this system is

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shown in fig 9.5. The MTK-2 (GOST 13052-67) primary five-character code of the telegraph unit (TA) is converted in a code converter into a seven-element code. Then the character combinations enter the radio transmitter via a distributor. At the same time the combination of characters is transmitted, it is "stored" (memorized) in the memory [14]. At the receiving end, after 7/5 code conversion into five-element code, start and stop messages are added and the character combination enters the TA, and with an "Error" signal an interrogation is made for its repetition by the radio transmitting station.

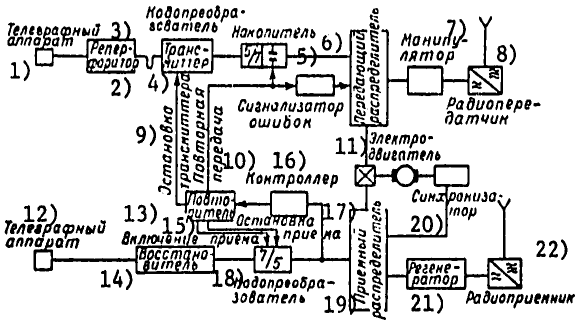

Figure 9.5. Block Diagram of TOR APD System

Key:

1. Telegraph set
2. Repuncher
3. Code converter
4. Transmitter
5. Memory
6. Transmitting distributor
7. Keyer
8. Radio transmitter
9. Stop transmitter
10. Repeated transmission
11. Motor
12. Telegraph set
13. Turn on reception
14. Restorer
15. Repeater
16. Controller
17. Stop reception
18. Code converter
19. Receiving distributor
20. Synchronizer
21. Regenerator
22. Radio receiver

Employed in the TOR unit is the time principle of channel multiplexing, making it possible effectively to utilize the power of the radio transmitter, as well as to improve the fidelity of transmission, since start and stop messages are absent in the character combinations in the radio channel.

In another variant of the TOR APD system, employed also for operation in an HF radio channel, a five-element code is used. In this system the monitoring and identification of distorted character transmission are performed with

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reference to the form of messages received. Each of the messages received is compared with a control pulse whose length is two- to threefold smaller than the length of a unit message. A plus message is considered undistorted and is admitted for reception upon the condition that its envelope is at all points greater than the plus control pulse. Two types of messages are compared, a plus and minus. Distorted characters are interrogated through the return channel.

In the TOR APD system is employed parallel entry of up to five lines with pulsed control. The TOR (ARQ) system is used in ship HF radio communications lines [35]. Whereas without the TOR system, in HF radio telegraph lines, errors occur in one out of 1000 or 100 characters, with the TOR system a character with an error arrives approximately in 10^{-3} to 10^{-5} of those transmitted. The "Sokol-MR" APD is employed in the MMF.

9.3. Communications Terminal Equipment and User Complexes

It is possible to include the following among terminal equipment for the preparation of primary documents and for obtaining information from a computer at an ASU operator's work place: card punchers, tape punchers, typewriters, equipment for preparing data on punched cards and punched tape, readout equipment, telegraph sets (roll and tape), transmitters, alphanumeric printers (ATsPU's), alphanumeric tape recorders (ATsRL's), terminals and displays. These devices subject information to various types of conversion in order to put it into a form suitable for entry into a communications channel directly in the ASU's computer.

In an ASU, for the preparation of documents various methods and facilities can be employed. A considerable portion of these is included in the set of external equipment arriving along with the computer [79].

Card punchers are designed for recording information in the form of punched holes in cards. They are divided by operating principle into single- and double-cycle. Of single-cycle punchers at the present time are used numeric punchers of the PF-6 type and type PA 80-2 alphanumeric punchers, and of double-cycle, type PD 45-2 punchers.

Tape perforators are designed for recording information on punched tape. Punching is done in five- and eight-bit code on punched tape 17.4 and 25.4 mm wide. The form, dimensions and position of holes in the tape conform with GOST 10860-68.

Readout equipment is employed for reading out information from punched cards and punched tape, for preparing data and for transmitting information. These devices are divided into contact, pneumatic and photo-optical. The photo-optical method of reading out is based on a change in the resistance of a photocell under the influence of light flux, thereby creating an electrical signal. The "Ridmom-40" photo-optical reader makes it possible to read zero to 40 lines per second in the start-stop mode, and 150 lines per second in the continuous mode. Included among high-speed readers is the FS-1501

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type photoelectric reader, used for reading information from punched cards and for entering it into a computer. The ER-300 unit for reading punched tape makes it possible to read and enter information into a computer from punched tape. The reading speed in the start-stop mode is zero to 150 or zero to 300 characters per second, and 275 or 550 characters per second in the continuous mode.

Computer Input/Output Printers

These include the "Konsul" type typewriter (CSSR). These typewriters, simultaneously while performing their key functions (information input/output), print information in the form of a typewritten text. An IBM (USA) typewriter has a keyboard for printing in 18 languages and makes it possible to correct errors. The number of keys on modern typewriters equals 46 (GOST 14289-69).

The "Videomon" type 343 (ATsPU-343) printer makes it possible to print lines with 20 to 80 spaces. With an 80-space line the printing speed is 356 lines per minute, and 1110 lines per minute with a 20-space line. On this machine it is possible to print simultaneously six copies on paper 10 and 25 cm wide.

Telegraph Units (Teletypes)

These are designed for transmitting information in communications systems. They are widely used for communication with ASU computers. Telegraph units (TA's) can be of the tape and roll type. Tape types, used for short texts, have not become widespread in ASU systems. Roll-type TA's are used for large data arrays. RTA-6 units have become most widespread among domestic roll-type units. A new domestic model is the RTA-7B. It has an operating speed of 400, 600 and 800 characters per second. Its correcting capacity for fringe distortion (at all operating speeds) is as high as 45 percent. Fringe distortion at the TA transmitter's output is not greater than two percent, and its correcting capacity with regard to fine subdivisions is not worse than 10 percent.

At the present time in the country's subscription telegraph network roll-type T-63 (RFT) TA's have become widespread.

Transmitters

These carry out the automatic transmission of texts by means of TA punched tape or of texts obtained by them directly in the process of receiving telegraph information. A transmitter consists of presetting, distributing, tape transport and driving mechanisms. They are part of complete TA's.

User Console (Terminal)

Sometimes this is equal to a user's station. It is equipped with a complex of data input/output units and enables a user to exchange information with a remote computer or several similar users through communications channels.

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For the transmission of data a console can have a keyboard, a set of buttons, equipment for reading punched tape, magnetic tape, and the like; and for reception, printers (TA's, PN's [expansion unknown] and ATsPU's), perforators, recording units, screens, graph plotters, and the like. An "Intellektual'nyy" [Intelligent] user console can have a moderate-size computer for processing transmitted or received information. A user console can include modems, buffer units, units for improving transmission fidelity, call equipment, and the like. For example, included in the series 1050 user console (IBM) are card readers, a card punch, punched paper tape readers, a tape punch and a printer. The operator by means of a modem connects the user console to the computer or to other user consoles.

The type TA-600 data transmission user console (station) makes it possible to transmit data to a remote user or computer. It includes a control and error correction block, a TAM-600 modem, an input unit with a "Ridmom-300" or ER-300 reader, an output unit with a FACIT 9060 or PL 150 punch, and a telephone set.

The key technical parameters of some user consoles (stations) are indicated in table 9.2.

Table 9.2.

1) Тип абонент. ского пульта	2) Шифр	3) Канал	4) Способ передачи	5) Скорость, бит/с	6) Код	7) Длина блока, бит	8) Длина знака, бит	9) Защита от ошибок, проверка знака
10) ТАП-70	ЕС-8570 11)	13) Коммутируемые и некоммутируемые телефонные и телеграфные каналы	15) Полудуплексный старт-стопный	17) 100 (10 зн./с)	19) КОИ-7	21) 105 зн. (длина строки)	8	23) Проверка знака, стопа и блока
ТАП-2	КС-8502 12)	То же 14)	16) Полудуплексный синхронный	200	20) 5, 6, 7 и 8 эл.	260 и 140	5, 6, 7 и 8	24) С запросом повторения и проверка на четность
ТАП-3	ЕС-8502	Коммутируемые и некоммутируемые телефонные каналы	То же	18) Прямой канал 600 и 1200 обратный 75	То же		То же	То же
ТА-600	ЕС-8502	То же	»	То же 75 и 200	»	260 и 140 200	22) Проверка на четность	Проверка на четность

[Key on following page]

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Key:

1. Type of user console
2. Code
3. Channel
4. Method of transmission
5. Speed, bits/s
6. Code
7. Length of module, bits
8. Length of tag, bits
9. Error protection, tag check
10. TAP-70
11. YeS-8570
12. KS-8502
13. Switched and unswitched telephone and telegraph channels
14. Ditto
15. Semiduplex start-stop
16. Semiduplex synchronous
17. 100 (10 characters/s)
18. Forward channel--600 and 1200; return channel--75
19. KOI-7
20. 5, 6, 7 and 8 elements
21. 105 characters (line length)
22. Parity check
23. Tag, stop and module check
24. Repetition interrogation and parity check

User Screen Console (Display)

This has a screen and resembles an ordinary television receiver. Data output from the computer at the operator's request is entered on the console's cathode ray tube. Here the maximum entry rate is conditioned by the capabilities of the communications channel. Information for electronic consoles and which requires storage is recorded on magnetic disks and is stored in the form of a data "bank" (files). The IBM2314 disk unit of this type holds 233 million characters (bytes) of information.

The average time for the retrieval of data stored in computer files is on the order of 75 ms [35]. A user screen console is furnished with a keyboard, by means of which the operator enters an interrogation into the computer, adds new data and refines existing data. Screen consoles make it possible to reproduce not only alphanumeric information, but also analog data, since on the screen can be displayed any outline sketch, diagram or figure. Furthermore, a light pen (electric needle) is often used, which makes it possible to draw necessary lines or write down any coded output data. The computer can determine the position of the pen by determining its current coordinates. A light pen is often used in combination with a foot pedal or keyboard. Sometimes the screen console's keyboard is combined with various templates and stencils for reproducing graphic data elucidating the situation in the travel of units (vessels or ships). Dot-type screen consoles make it possible to work with quite different types of information, periodically refining the image by means of a computer or control unit connected to the user console [35].

For filling a screen with 1200 characters of an alphanumeric text 4 s are required, and for representing an outline drawing in the form of dots in an 800 X 800 matrix 4.5 min are required when operating through a telephone communications channel. For shortening the time for the display of figures, consoles are placed near the computer, and broadband communications channels are used.

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A type AR-62 (YeS-8562) user screen console is shown in fig 9.6 [photograph not reproduced]. It is connected to a remote computer through a telephone channel.

Facsimile Telegraph User Consoles

These are designed to transmit and reproduce documents, situation charts (ice, weather), and the like. The document can be transmitted in analog or digital form. Digital coding is used in the majority of facsimile telegraph transmitters. In this case the information is transmitted in the form of a black and white or half-tone image. Through a telephone channel a page of text measuring 12 X 27.5 is transmitted in 5 to 6 min [35, 47]. Higher facsimile telegraph speeds can be achieved by using communications channels with high carrying capacity.

Conversation and Call Unit

The type TTN-4800 conversation and call unit makes it possible to call and carry on a service conversation in APD systems operating with unswitched telephone channels. It also accomplishes remote monitoring of a modem. The telephone capsule in the microtelephone receiver makes acoustic calling possible.

9.4. Automation of Information Transmission Processes in Marine Radio Channels

One of the most important trends in the creation of the communications system for the "Morflot" ASU and the MRKh ASU is the development and introduction of methods and automation equipment enabling long-range round-the-clock communications with craft. In the development of automated methods of communicating with craft, it is necessary to take into account the necessity of transmitting considerable volumes of information through radio channels of low quality under conditions of interference, while also taking into account the limitations imposed by the international nature of radio communications.

The creation of an automated system for communicating with craft is being accomplished by the gradual introduction of new radio communications facilities with a subsequent changeover to total automation. Some automation equipment, such as the system for automatic selective calling of craft and the improved-fidelity printing equipment, is being used at the present time also. The data transmission equipment (APD) discussed in sec 9.2 should be numbered among the equipment which will make it possible to partially automate marine radio communications. The input and output of information in MTK-2 code (GOST 13052-67) at a rate of 50 bauds will make it possible to link marine APD with land telegraph networks of the subscription telegraph (AT) and international "Telex" system.

APD will produce the best result when operating with the new inventory of marine channel-forming equipment—radio receivers of the "Shtorm" type and radio transmitters of the "Brig" and "Korvet" types, enabling scan-free and trim-free single-sideband radio communications. Through such HF radio lines

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at a preprovided frequency can be accomplished the programmed gathering of information from craft for purposes of the "Morflot" ASU and MRKh ASU. In this case the marine radio receiver and the APD are in the continuous reception mode. At a time determined by an interrogation routine, the coastal radio station transmits a selective call signal (a five-digit number) to the vessel and by supplying a special signal automatically turns on the marine APD transmitter and copies the preprepared information. When necessary, communication through the radio line with the APD can be established at the vessel's initiative.

The future development of marine radio communications requires a systems approach to the solution of the automation problem. The complex of communications facilities entrusted with enabling the total automation of processes relating to communications with craft will include, in addition to APD, the following [48]:

A system for automatically entering into communication (an AVS) with equipment for the remote control of marine channel-forming equipment.

A system for automatic formation of a communications channel between a shore user and a vessel.

A marine system for the automatic gathering and preparation for transmission of information for the ASU.

The key requirements of the AVS system are the enabling of automatic selective calling in the shore to ship, ship to ship and ship to shore directions, and of group calling of vessels located in a specific geographic area, or of conference calling. In addition, in the AVS system provision is made for the transmission of additional information in the form of remote control commands making it possible to form the necessary kind of communications while turning on and switching the appropriate channel-forming equipment on the vessel. The AVS system is designed also for transmitting information relating to navigation safety. It will have parameters regulated on an international basis.

For the normal functioning of the "Morflot" ASU and the MRKh ASU, it is necessary to automate the process of selecting and setting up the optimal radio channel in the shore to ship direction. For this purpose, at coastal zone radio centers a special complex for communications with a computer will be employed. One variant of such a complex is shown in fig 9.7 [48]. A variant of the functional diagram for the interrelationship of computer elements (a special processor) of a complex for communicating with raw data sources and input/output information sources is shown in fig 9.8. Entering the memory of the radio center's computer are orders for communications with vessels located in its operating area. The computer by means of available information on the location of the required vessel and the parameters of its travel determines its calculated location at the moment for communication. Then, taking into account the data of a radio forecast and information on the workload of the radio center's channels, the computer calculates the operating frequency and via control modules issues commands for the preparation of

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transmitters, receivers and the appropriate antennas. After selection of the optimal radio channel, the vessel is called by means of the AVS system, the channel-forming equipment is automatically switched to the operating channel and information is copied (or transmitted) by means of the APD. It should be mentioned that a similar system for automatic linking of marine channels with the "Telex" network with automatic entry into communication has already been realized and is being used at the "Göteborg Radio" radio station.

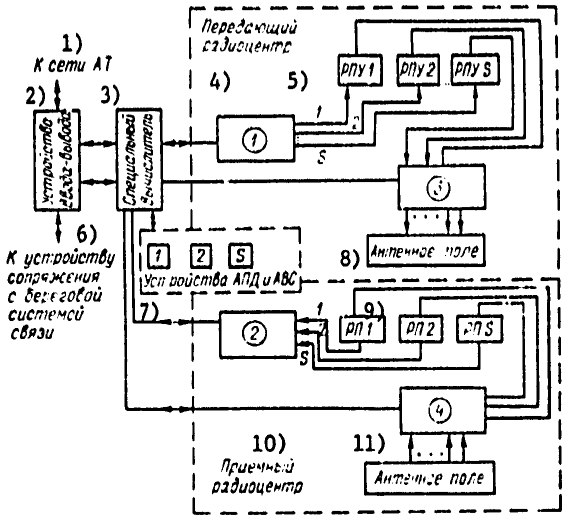

Figure 9.7. Functional Diagram of Automation of Selection of the Optimal HF Radio Channel (Variant): RPU--radio transmitter; PR--radio receiver; 1--radio transmitter channel switching unit; 2--radio receiver channel switching unit; 3--transmitting system switching unit; 4--receiving system switching unit

Key:

1. To AT network
2. Input/output unit
3. Special processor
4. Radio transmitting center
5. RPU1
6. To unit for linking with coastal communications system
7. APD and AVS units
8. Antenna field
9. RP1
10. Radio receiving center
11. Antenna field

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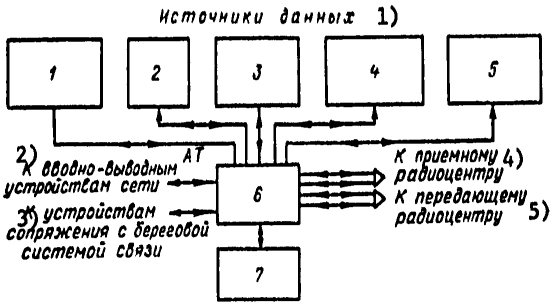

Figure 9.8. Functional Diagram of Interaction of Communications Computer with Data Sources and Control Units (Variant): 1--direct data on vessel's joining communication zone; 2—position of vessels; 3--radio forecast data; 4--data on radio transmitting center; 5—data on radio receiving center; 6—special processor (computer); 7--unit for signaling channel quality

Key:

1. Data sources
2. To network input/output units
3. To units for linking with coastal communications system
4. To radio receiving center
5. To radio transmitting center

The automation of the process of gathering and preparing for transmission marine information is based on linking radio communications facilities with devices for documenting the operation of marine complexes for the automation of navigation, power plants and other sources of information characterizing the production activity of the vessel. In documentation units is concentrated all the information to be transmitted to the coastal administrations of the ASU system ("Morflot," "Parokhodstvo" [Shipping Line], etc.) and the MRKh OASU. Marine information sources operate in MTK-2 code (GOST 13052-67) and lead out to marine communications facilities via buffer units for linking with APD. In fig 9.9 is shown a variant of a functional system for the interaction of facilities for the automatic gathering and preparation of information with marine communications facilities [48]. With the existence on the vessel of several posts for controlling different types of production operations (on large fish-finding and fish-processing vessels), the information arriving on vessels, according to the data of foreign publications, is automatically distributed through control post user consoles.

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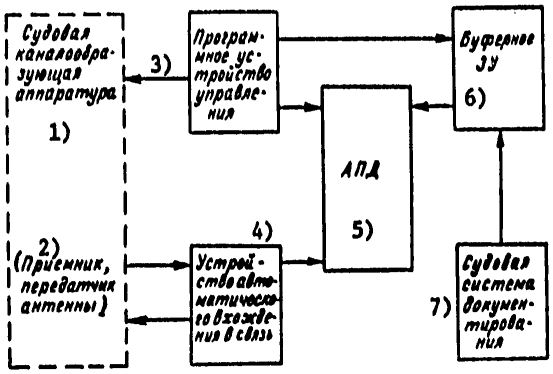

Figure 9.9. Functional Diagram of Automatic Gathering and Transmission of Information on a Vessel (Variant)

Key:

1. Marine channel-forming equipment
2. Receiver, transmitter, antennas
3. Program control unit
4. Equipment for user's entry into communication
5. APD
6. Buffer memory
7. Marine documentation system

At the first stage of the introduction of automated communications facilities for vessels, the foundation is being laid for the transition to a totally automated system for communications with vessels based on the combined utilization of both traditional radio communications lines in all frequency bands, and satellite communications systems.

Chapter 10. Automation of Processes of Receiving Information and Calling Vessels and Ships and of Transmitting Alert and Distress Signals

The automatic selective reception of printed information and selective calling in marine radio communications make possible speed of radio communications and improve its efficiency. Automatic selective reception makes it possible to provide the capability for the automatic reception of information and the routine calling of stations or a number of marine stations without the intervention of a radio operator. Thereby are eliminated the inconvenience and overloads experienced by marine stations forced to receive all information and monitor all calls.

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10.1. Radio Telephone and Radio Telegraph Equipment for Automatic Selective Calling of Vessels and Ships

The international nature of marine radio communications has made it necessary to standardize the technical and operating parameters of equipment for automatic selective calling of vessels. The International Radio Consultative Committee has determined the frequencies at which selective calling can be carried out, and has also determined the key technical characteristics of selective call signals and the principles of the distribution of code signals between countries and the procedure for their use.

The following frequencies have been assigned for selective calling: 500 kHz; 2170.5, 4125, 4419.4, 6521.9, 8780.9, 13,162.8, 17,294.9 and 22,658 kHz; and 156.8 MHz. The selective calling call signal is formed of digits from zero to nine, whereby the selective calling call signal of a marine station consists of five digits, and of a shore station, of four. For the simultaneous calling of groups of vessels, a five-character signal can be used, consisting either of one digit repeated five times, or of two repeated alternately.

Audio frequency pulses used for forming digits and for the selective calling of a vessel or coastal station are selected in the following manner: Corresponding to digit 1 is a frequency of 1124 Hz (F_1); 2--1197 Hz (F_2); 3--1275 Hz (F_3); 4--1358 Hz (F_4); 5--1146 Hz (F_5); 6--1540 Hz (F_6); 7--1640 Hz (F_7); 8--1747 Hz (F_8); 9--1860 Hz (F_9); 0--1981 Hz (F_{10}). The sign for the repetition of digits has a frequency of 2110 Hz (F_{11}).

Selective calling can be perfored with and without determination of the calling station on the vessel. A time chart for the transmission of selective calling signals with determination of the calling station [29] is illustrated in fig 10.1.

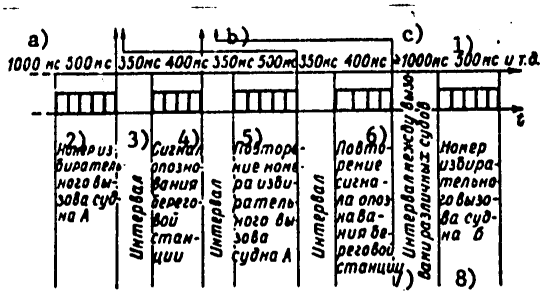

Figure 10.1. Time Chart for Transmission of Selective Calling Signals with Determination of the Calling Station: a--acoustic or optical indicator triggers with proper reception on vessel A; b--display or registering of signal for identification of coastal station with proper reception on vessel A;

[Caption continuation and key on following page]

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c--acoustic or optical indicator triggers with proper reception on vessel B.

Key:

1. 500 ms, etc.
2. Selective calling number for vessel A
3. Pause
4. Signal for identification of shore station
5. Repetition of selective calling number for vessel A
6. Repetition of signal for identification of shore station
7. Pause between calls for different vessels
8. Selective calling number for vessel B

The duration of the transmission of a pulse for each frequency should be 100 $\pm$ $\pm$ 10 ms with a pause between pulses of 3 $\pm$ 2 ms, and with conference calling, 17 $\pm$ 1 ms with a pause of 1 ms. The selective calling signal is transmitted twice with a pause of 900 $\pm$ 100 ms between the end of the first signal and the beginning of the second. The pause between successive calls of a shore station for different vessels should be a minimum of 1 s.

After the selective calling signal additional information can be transmitted, consisting of four digits for identification of the coastal calling station, or of two zeros, followed by two digits for indicating the number of the transmission channel through which the marine station should transmit a reply.

The special call "To All Vessels," designed for triggering receiving selectors on all vessels, consists of the continuous transmission of a series of all 11 audio frequencies (from F_1 to F_{11}). The total duration of a conference calling signal should be not shorter than 5 s.

In the USSR and other countries devices have been created for the selective calling of vessels and the transmission in conference networks of information intended for a specific vessel or group of vessels. The "Selektor" selective calling equipment is being manufactured for vessels of the USSR MMF and MRKh.

A computer is used for controlling U.S. Navy radio stations in selective calling systems. Provided in the computer's memory is an additional storage unit for each ship operating with a specific coastal radio station.

The computer checks the information arriving for transmission and with reference to an address group determines to which vessels and ships it is necessary to transmit it. Then in the computer is formed a list of addresses and in the heading of telegrams individual indicator groups are entered, through which the selective calling receiving unit of each individual vessel automatically identifies the radio message addressed to it and carries out automatic reception with the printer.

This radio traffic procedure relieves vessels and ships of superfluous work in the receiving of all radio messages traveling through the radio network and stops the dissemination of official information to addressees to whom it

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is not addressed. In order to notify a vessel or ship about radio messages missed because of poor transmission or the failure of equipment, the coastal radio station from computer data periodically several times per 24-hour period transmits the serial numbers of telegrams transmitted in the network with the call letters of the correspondents. The correspondents (vessels and ships) confirm the receipt of radio messages through a return radio telegraph communications channel. The numbers of the transmitted and received radio messages are compared in the computer, those not received are identified and they are repeated.

In the case of interrogation for the repetition of a missed radio message, the reply will be transmitted only to a single addressee. The operator is notified beforehand by special signals regarding the arrival of a radio message at the vessel's or ship's address. The selective calling unit is completely electronic. It is made out of standard integrated circuits and semiconductor logic modules and is characterized by high reliability, speed of response and compactness.

The unit on vessels, in keeping with the address group, automatically sets the printer into operation. At the end of the receipt of the message, the unit is returned to its original position to await the next radio message. The signal regarding the end of a message arrives at the vessel from the transmitting radio station.

A similar selective calling unit, of the "Sicable" type, has been developed for ships of the English navy. This unit conforms in its parameters and procedure for utilization to MKKR requirements for selective calling systems. In this system each vessel and ship is assigned a five-character code group similar to the international call sign, and coastal radio stations are assigned four-character groups.

Provided in radio transmitters and receivers on shore and on vessels is a selective calling receiving mode, as well as the transmission and reception of alert signals. For example, in Norway the new EB-1500 single-sideband telephony marine radio transmitter has been developed, which is part of the marine communications complex. Included in this complex, in addition to the EB-1500 transmitter, are an automatic alert signal receiver and telegraph key, and also selective calling equipment.

Coastal radio stations can transmit a radio call signal simultaneously at eight HF band frequencies, which makes it possible to ensure the reception of a call signal by ships and vessels in various sailing areas. For these purposes, on vessels and ships provision has been made for the installation of eight-channel radio receivers, which together with a decoder enable automatic reception at several frequencies arriving at the area of location of the vessel.

The FRG has developed and put into service its own selective calling system for vessels of the maritime fleet [46]. This system automates marine radio communications channels and facilitates the duties of radio operators on

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vessels. Each vessel in the system has been assigned a five-character identification number. This number and four more digits carrying additional information in coded form are transmitted by radio in the form of a series of audio pulses. The frequency range of these pulses covers an octave (1124 to 2110 Hz). At the coastal radio station the digits are entered via a keyboard into the selective call transmitter.

The USSR "Selektor" equipment complex for selective calling of vessels, which was manufactured prior to 1978, consists of a "Selektor-P" transmitter and a "Selektor-SM" receiver. The structure of signals of the "Selektor-P" selective calling unit, designed to form pulse-frequency signals for the selective calling of vessels, is illustrated in fig 10.2 [27], and its functional diagram in fig 10.3. This unit makes possible visual indication of dialed digits of the code number and the ability for manual and automatic resetting of the dialed number. The "Selektor-SM" receiver is a decoder of audio frequency code signals for individual and multi-channel conference calling, as well as for single-channel microwave conference calling.

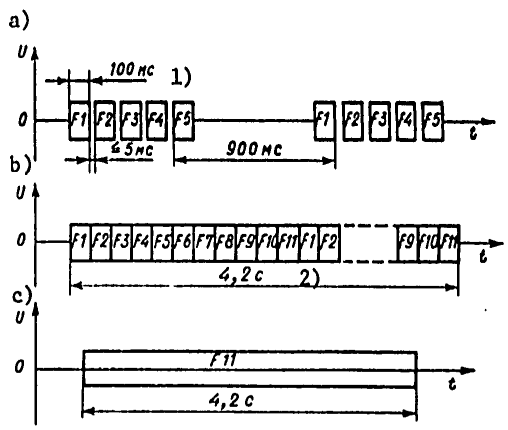

Figure 10.2. Structure of Selective Calling Signals: a--for individual calling (IV); b--for multi-tone conference calling (MTsV); c--for single-tone conference calling (OTsV)

Key:
1. 100 ms
2. 4.2 s

Under development at the present time is a new selective calling system for USSR vessels, which satisfies the requirements of the MKKR.

This new digital selective calling system (TsSIV), in addition to transmitting the number of the station called, should also ensure automation of the communications process in off-duty periods.

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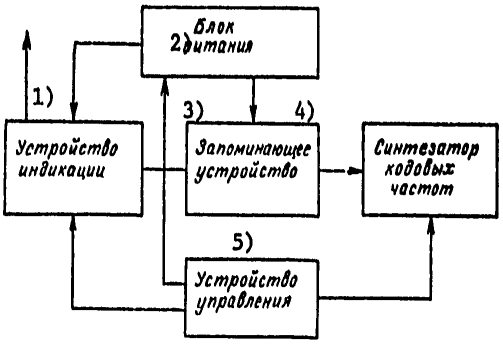

Figure 10.3. Functional Diagram of "Selektor-P" Unit

Key:
1. Display
2. Power supply
3. Memory
4. Code frequency synthesizer
5. Control unit

International systems for automatic entry into communication (AVS's), according to a decision of the 23d MKKR Plenary Assembly, must be suited for utilization in all marine frequency bands and by all categories of users in various variants (from the simplest selector performing the functions of a bell or light signal, to a complex system for switching marine radio and terminal equipment).

The assembly determined that the call sequence of the AVS system must be transmitted in binary code, have a duration of less than 2.5 s, and be made up of a variable number of text elements with an indication of the urgency and priority category. The assembly determined the following format for the call sequence for AVS systems: address, message 1, message 2,..., message n, end of call sequence.

Agreement was reached that the new international system for selective calling of vessels must be digital, since this is necessary for the automation of communications with craft. The employment of a seven-character digital identification system was recommended, where the first digit (or first few digits) indicates the country, in conformity with MKKTT's worldwide numbering plan. This seven-digit number should be considered the terminal number of a world telegraph system subscriber. During the transition period the seven-digit calling system must be combined with the five-character systems used in telephony and printing telegraphy.

The number of messages in the call sequence format can be arbitrary. The key messages are: the identification number per se (address of the calling

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station); urgency category--a message indicating the priority level or place in line of the call; distress message, containing information on the position of the vessel and the nature of the distress (latitude is transmitted in five digits, longitude in six, and nature of the distress with one digit); and remote control signals for forming the marine channel-forming apparatus, as well as the frequency for transmission and reception of the communication.

The end of the call sequence is a signal whereby the marine equipment ceases the transmission of commands.

In the case of distress, it is recommended that a shortened call sequence format be transmitted, a distress signal, the identification number of the vessel in distress, information on the nature of the distress, and the end of the sequence.

10.2. Equipment for the Automatic Transmission and Reception of a Radio Telephone Alert Signal

The "Vyzov" automatic radio telephone alert signal transmitter is an attachment for the radio telephone transmitter's modulator. The "Vyzov" automatic marine transmitter has a matching unit which makes it possible to connect its output to the input of various transmitters. It makes it possible to modulate the carrier frequency of a 2182 kHz transmitter with two alternating audio frequencies (1300 and 2200 Hz), each 0.25 s long.

This automatic transmitter is turned on by order of the captain with an "Alert" tumbler switch, with the transmitter pretuned to a frequency of 2182 kHz. With the tumbler switch in the "On" position, the transmitter operates automatically with a 45-s "Alert" signal and a 54-s pause cycle. The operation of this automatic transmitter can be monitored with headphones connected to the automatic transmitter's T jack.

The "Avral-1" [29] automatic radio telephone alert signal receiver is designed for the automatic tracking and reception of alert signals transmitted at the international call and distress frequency of 2182 kHz.

The "Avral-1" receiver, tuned to a frequency of 2182 kHz, receives and amplifies the entire spectrum of modulated oscillations and separates distress signal pulses (1300 and 2200 Hz). Audio distress signal pulses are converted into d c. pulses, which enter a time gate. The time gate separates only those pulses which match in length the parameters of the international alert signal.

The double-frequency alert signal pulses are recorded in the reservoir capacitor of the pulse registering stage. With the arrival of four to six double-frequency pulses, the potential of the capacitor becomes equal to the voltage for triggering the cascade and the alert signaling system is turned on.

If pulses enter the input of the time gate, which differ in length from those of an alert signal, or follow with long pauses or a break in order,

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then an individual monitoring stage causes resetting of the reservoir capacitor's potential, as the result of which the circuit returns to its initial situation.

For purposes of ensuring the reliability of the reception of alert signals, after the receiver is turned on and it heats up, tube currents are checked with a test instrument and by pressing a "Test" button a test is made of the working order of the receiver from an alert signal imitator. At the end of the test the "Record Alert" button is pressed and the receiver enters its starting state for on-duty reception. The mean cycle between failures for the "Avral-1" receiver is 1600 h.

The "APM-3" automatic radio telephone alert signal receiver is tuned to a frequency of 500 kHz and receives class A1 and A2 oscillations. The sensitivity of this receiver is 100 μV and it is powered with 120/220 V, 50 Hz or 110/220 VDC. The storage battery for the alert bell is a 24-V one. The overall dimensions of this receiver are 235 X 165 X 290 mm, and it weighs 7.8 kg.

The "Sirena" standby marine communications complex has a transmitter with five fixed frequencies: 410, 425, 454, 500 and 512 kHz. The receiver operates over an even 410 to 540 kHz range. Its oscillation classes are A1 and A2. The power of the transmitter in the A1 mode is 32 W, and 40 W in the A2 mode. The sensitivity of the receiver is 20 μV. It is powered by a 20-VDC storage battery or from 220 VAC. The power requirement of the transmitter is 290 W. It has an automatic transmitter for an alert and "SOS" (letters "DYe") signal, with the call letters of the vessel and manual setting of the latitude and longitude of the distress event.

The "Prizyv" emergency deck radio station has a transmitter with fixed frequencies of 500, 2182 and 8364 kHz and a receiver with frequencies of 500, 2182, and 8330 to 8740 kHz. Its transmission classes are A2 and A3 (the latter at a frequency of 2182 kHz). The power of the transmitter is 3 W. Overall dimensions are 340 X 510 X 365 mm, and its weight is 20 kg. Its antennas are telescoping and of the coil type.

Section Four

Effectiveness of Communications

Chapter 11. Methods of Rating the Effectiveness of Communications

By the effectiveness of a facility, complex, system or process is customarily meant its ability to fulfill the objectives set for it, for achieving a set goal [8, 9, 78].

Communications as an information process has the goal of transmitting (delivering) from a sender to a receiver information required for the purpose of controlling vessels or ships in the solution of the problems facing them. The purpose of a communications system is to enable the transmission (delivery) along assigned routes of the necessary information flows with the required

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quality under the anticipated conditions for carrying out communications. For the purpose of achieving this goal, communications system problems are formulated, which determine which information must be transmitted, along which routes (from whom, to whom), in what amount, and with what kind of quality. For the fulfillment of these objectives a communications system is created and improved, and when it is in existence communications are planned, i.e., a determination is made of what is to be done, by whom, how and by what deadline.

The measures planned are implemented by organized work in preparing the system for functioning. The prepared communications system is utilized for transmitting information required for controlling vessels and ships. Functioning of the system in the established modes requires the performance of measures for ensuring its operation and monitoring the state and utilization of communications. In necessary instances measures are taken to alter the structure of communications networks (or of a system), information flows and their transmission, and communications channels and facilities, as well as other measures relating to the control of the communications system.

Thus, the entire set of operations and measures indicated, relating to the creation, improvement and preparation of a communications system, and to its functioning, security and utilization, is aimed at fulfillment of the objectives of the communications system and the achievement of the purpose of communications, i.e., is aimed at the effectiveness of communications.

For a quantitative evaluation of the effectiveness of communications, it is necessary to rate its reliability, fidelity, efficiency, and, in necessary cases, its secrecy.

11.1. Rating the Reliability of Communications

By the reliability of communications is meant the property of ensuring continuous control under any circumstantial conditions.*

Radio communications with vessels and ships carried out over very great distances represents a highly complex process by virtue of the influence of a great number of diverse factors which are at work simultaneously. Therefore, it is advisable to rate quantitatively the reliability of communications along a single route by the ratio of the number of messages received with permissible distortion at the receiving point to the number of messages transmitted:

$$P_{\text{н}} = \frac{A - \sum_{i=0}^{k} a_i}{A}, \tag{11.1}$$

*The concept "reliability of communications" is considerably broader than the concept "reliability of communications facilities." Theoretical questions relating to the reliability of communications facilities are developed on the basis of reliability theory.

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where A is the number of messages transmitted at the transmission point along a given route; a is the number of messages lost along this route as the result of their non-reception or of heavy distortion because of inadequacy of the signal field, interference at the reception point, improper operation of equipment or for another i-th reason. There can be k reasons, i.e., $0 \leq i \leq k$.

The magnitude of P_n is of a probabilistic nature. It is called the probability of reliable communications along the route in question.

The factors influencing radio communications and governing its reliability can be grouped and evaluated in the following manner:

1. The group of factors, discussed in detail in chaps 2 and 3, governing the capability of establishing and carrying out radio communications between transmission and reception points (radio transmitters and receivers, the ionosphere, different kinds of radio interference, etc.). The effects of these numerous factors are expressed numerically by the total degree of probability of carrying out communications under specific conditions for assigned communications ranges, $P_{d.sv}$.

2. The group of factors governing the fidelity of communications at the range realized.* As follows from a consideration of radio communications lines (chaps 2 and 3), the fidelity, range and continuity of communications are inseparable. An increase in range entails a reduction in communications fidelity, and the tolerable limit of this reduction practically determines the range possible under specific conditions.** Thus, the level of communications fidelity characterizes its reliability. The fidelity of communications is rated quantitatively by the fidelity factor, K_{ver} (ratio of properly received characters to all characters transmitted), and the distortion factor, K_{isk} (ratio of distorted or non-received characters to all characters), the probability of character distortion, P_{isk}, and the probability of accurate communications, P_{ver} (the probability that a message will have a permissible number of distortions).

3. The group of factors governing the proper operation of communications channels, i.e., the operating reliability of transmitting and receiving circuits, taking into account the operations of personnel in tuning and controlling communications facilities, or, as it is customarily called, operating reliability,

*By the fidelity of communications is meant the accuracy in the reproduction of messages received in relation to those transmitted.

**An exception is satellite communications. The employment of satellites for communications has no range limitations, and high communications fidelity is maintained.

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which can be rated by the probability of the proper operation of a communications channel, P_{isp}.

The operating reliability is often rated by the working order factor, the KID--the ratio of the time the channel is in good working order to the entire time during which it should be in good working order.

The reliability of communications with naval ships during the course of combat operations depends also on intentional jamming and enemy attacks on the communications system and measures for protecting it from this influence. Without discussing these questions in detail, it should be mentioned that the effectiveness of the creation of radio interference by an enemy is rated by the probability of the creation of radio interference, P_{nom}, and the going out of order of facilities included in a communications channel, by probability P_{vyv}.

Taking into account all factors influencing radio communications, it is possible to estimate the probability of reliable radio communications with vessels along a single route by the equation:

$$P_{н} = P_{д.\,св} P_{вер} P_{исп},$$

and the probability of reliable radio communications with ships by the equation:

$$P_{н} = P_{д.\,св} P_{вер} P_{исп} (1 - P_{пом}) (1 - P_{выв}). \tag{11.2}$$

Strictly speaking, in equation (11.2) are indicated the probability of interdependent events, but for practical calculations it is possible to assume their independence.

From an analysis of factors influencing the reliability of radio communications with vessels, it follows that the most important lines along which it can be achieved are the following: the employment of powerful transmitters and more sensitive receivers and directional antennas, and reduction of the level of interference from different sources at the reception point; the selection of radio frequencies by taking into account their transmission in a specific radio route, and for long ranges, also the proper selection of radio routes, i.e., the creation for long communications ranges of territorially spaced transmission points or receiving points; properly taking into account the state of the ionosphere, which is possible with accurate radio forecasts and monitoring of the state of the ionosphere; proper selection of the operating mode for radio communications channels; the employment of equipment with high noise rejection; the use of highly skilled operators; measures for handling enemy jamming; and measures for achieving power superiority of the communications signal over the noise signal at the receiving point, and other measures for combating enemy jamming.

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Improvement in the reliability, and especially in the fidelity of communications in automated systems is achieved, in addition, by special measures which considerably improve the quality of communications (cf. Section Three). For example, it has been demonstrated [18] in studies by the Soyuzmorniiproyekt [USSR Ministry of the Maritime Fleet State Planning, Design and Scientific Research Institute of Marine Transportation] that the employment of APD improves fidelity in HF radio channels from 10^{-1} to 10^{-3}, and on shore in wire channels, by two orders of magnitude on average (fig 11.1).

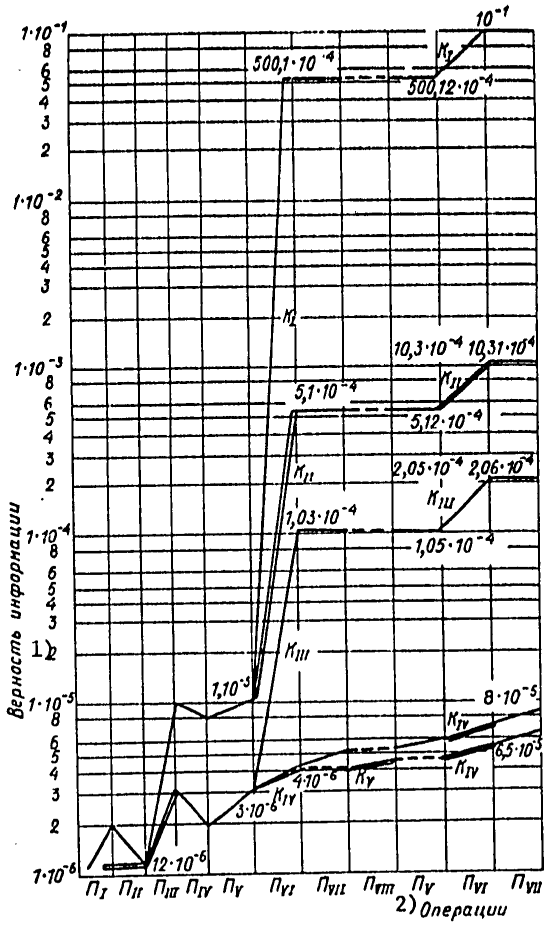

Figure 11.1. Distribution by Operations of Distortions Introduced in a Message in the Process of Transmission to the Addressee, in the Existing MMF System and in the Future "Morflot" ASU Communications System: _____ existing facilities,

[Caption continuation and key on following page]

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communications channels; ======= future communications facilities and channels; ------- sections in which the operation in question is absent. P_I--printing of original message; P_{II}--checking print; P_{III}--transferring message to medium; P_{IV}--checking text; P_V--distortion in transmitting equipment; P_{VI}--transmission of message through communications channel; P_{VII}--distortion of message in receiving equipment; P_{VIII}--distortion in message switching center; K_I--section for transmission of message through HF radio channel without APD; K_{II}--ditto, with APD; K_{III}--section for transmission of message through YeASS [Unified Automated System of Communications for the Country] channel without APD; K_{IV}--ditto, with APD; K_V--section for transmission of message in message switching center

Key:
1. Fidelity of information 2. Operations

The employment of marine satellite communications must be singled out as the most promising trend.

11.2. Rating the Efficiency of Communications

By the efficiency (speed) of communications is customarily meant the property of communications for the timely transmission and reception (delivery) of a message or for the carrying out of conversations, dependent on the need for control under specific circumstantial conditions.

The speed of communications along any route depends on the carrying capacity of channels, the skills of operators, the work load of subdivisions, and rules of the Station Operation Service (SES). Exerting an influence on it is the structure of the communications system (the existence of direct communications channels and retransmission points, the number of radio stations in the network, etc.) and the utilization of communications (size of messages supplied to communications facilities, correctness of addressing, and the like), and, in modern systems, the level of automation of information transmission processes and the operation of communications posts.

Speed can be rated quantitatively by the time a message travels, i.e., by the time from the moment the message enters the communications system at the transmission point to the moment the message leaves the system at the receiving point for handing to the addressee. The travel time is calculated by the equation:

$$t_{npox1} = t_{дост1} + t_к + t_{ус1} + t_{пер} + t_{ус2} + t_{р.к} + t_{дост2}, \qquad (11.3)$$

where t_{dost1} and t_{dost2} is the time for delivery of the message from the sender to the addressee; t_k and $t_{r.k}$ are the time for coding and decoding the message at the transmitting and receiving points; t_{us1} and t_{us2} are the time for transmission of the message at the communications units of the transmitting and receiving points; and t_{per} is the time for transmission of

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the message through the communications line; it depends on the size of the message, q , and the transmission rate, V_{per} :

$$t_{nep} = \frac{q}{V_{nep}} = \frac{q_{сл} + q_{загл} + q_{сооб}}{V_{nep}}, \tag{11.4}$$

where $q_{сл}$, $q_{загл}$ and $q_{сооб}$ are the size of official conversations, the official heading and the message.* Here a distinction is made between the technical transmission rate (cf. Appendix 1) and the operating transmission rate, V_{per} , which is determined by the capabilities of operators in transmission and reception of the text and its required processing at communications posts in keeping with SES rules.

Equation (11.3) can be written in the form:

$$t_{npox1} = t_{np1} + t_{nep} + t_{np2}, \tag{11.5}$$

where t_{pr1} and t_{pr2} are the message's travel time at the transmitting and receiving point.

The entire route of the message from the sender to the addressee can be divided into n sections with travel in each section of t_j . Thus,

$$t_{npox1} = \sum_{j=1}^{n} t_j. \tag{11.6}$$

But this is valid with the absence of message delays resulting from the operator's being busy, the operating frequency's being occupied and other reasons, and they are always present in real systems. Along its route in the communications system, a message can encounter up to k retransmission

*The value of the travel time is a random magnitude, and therefore a determination should be made of its mathematical expectation. If an assumption is made and processes of information travel are considered quasi-regular, then we will get the mean expected travel time in each section and for the communications system as a whole. As demonstrated by practice, such an assumption is acceptable.

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points and at each of $k + 1$ sections of the route be transmitted up to m times with the expectation in turn of transmission for a period of time τ, whereby the travel time at each retransmission point can be t_{pr}, and in sections communications can be lacking for a period of time of t_{ot}. Thus,

$$t_{прох} = t_{дост1} + t_к + t_{ус1} + \sum_{j=1}^{k+1} \sum_{i=1}^{\bar{m}} (t_{пер ij} + \tau_{ij}) + \sum_{j=0}^{k} t_{пр j} + \sum_{j=0}^{k+1} t_{от j} + t_{ус2} + t_{р к} + t_{дост2}. \quad (11.7)$$

Strictly speaking, with heavy loading of the communications system each value of t_{dost1} and t_{dost2}, t_{sh} and $t_{r.sh}$, t_{us1} and t_{us2} is increased by some value of τ, i.e., everywhere it is necessary to take into account the delay time. Consequently,

$$t_{прох} = t_{прох1} + \sum_{j=0}^{k+1} \sum_{i=0}^{a} \tau_{ij}, \quad (11.8)$$

where τ_{ij} is the delay time in travel of the message for the i-th reason in the j-th section, whereby $0 \leq i \leq a$ and $1 \leq j \leq k + 1$.

Time τ is also characterized by the probability of delay, $P(>\tau_д)$, by which is meant the probability that the message will be delayed for a time greater than the permissible, $\tau_д$. The delay time and probability are indicators characterizing the communications system in the transmission of an information flow, and chiefly the structure and organization of the service at communications posts. Therefore, in organizing communications one strives to minimize τ and $P(>\tau)$. They depend on the capabilities of the communications system, the organization employed and the utilization of communications, and the information flow along a specific route, and $P(>\tau_д)$, also on the requirements for speed of communications. Employing the mathematical apparatus of the queueing theory, it is possible to calculate the magnitudes of interest, $P(>\tau_д)$, in particular, by the equation:

$$P(>\tau_д) = P(>0) e^{-(s-\gamma)\frac{\tau_д}{\theta}} = \frac{\frac{y^s}{s!}\frac{s}{s-y}}{\sum_{i=0}^{k-1}\frac{y^i}{i!} + \frac{y^s}{s!}\frac{s}{s-\gamma}} e^{-(s-\gamma)\frac{\tau_д}{\theta}}, \quad (11.9)$$

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where s is the number of channels of a single route; Y is the load at the hour of maximum strain, in hours busy; τ_d is the permissible waiting time, in min (or s); θ is the average time for waiting for the end of the preceding broadcast at an arbitrarily chosen moment of time, in min (or s). The value of Y can be calculated by equation (1.1). We find the value of τ_d from equation (11.8):

$$\tau_д = t_{прох.д} - t_{прох1}. \tag{11.10}$$

The average time for waiting for the end of a preceding broadcast at an arbitrarily chosen moment of time depends on the nature of the distribution of the total time a channel is occupied in transmitting a single message, t_k:

$$\theta = \frac{1+\gamma^2_{t_k}}{2} t_k,$$

where γ_{t_k} is the variation factor for time t_k.

Under specific operating conditions, the time factor, γ_{t_k}, depends on variation in the size of the message in terms of the number of characters (digits, letters and official symbols) contained in it:

$$\gamma_{l_k} = \frac{\sigma}{\bar{l}_k}, \tag{11.11}$$

where σ is the root-mean-square deviation in t_k.*

With the distribution of t_k exponentially, $P(>t) = e^{-t}$, where $P(>t)$ represents the probability that the channel will be occupied for a length of time greater than t, $\gamma_{t_k} = 1$ and $\theta = t_k$. With a constant value of $t_k = \text{const}$, the values of $\gamma_{t_k} = 0$ and $\theta = t_k/2$.

*The value of γ_{t_k} can be calculated by the equation:

$$\gamma^2_{l_k} = \gamma^2_{гр} + \gamma^2_{зн} + \gamma^2_{гр}\gamma^2_{зн},$$

where γ_{gr} is the variation factor in the size of messages in terms of groups (words) and γ_{zn} is the variation factor for the size of a group (words) in terms of characters.

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On the basis of the above, it is possible to construct graphs and nomograms on which are shown the dependence of $P(>t)$ on the values of τ and θ in the form of their ratio, τ/θ, and on the value of S_i. For example, G.P. Zakharov and N.P. Varakosin have suggested nomograms and tables [23] for calculating the number of communications channels in running systems with a waiting period (fig 11.2). Nomograms for the calculation of systems which involve waiting, in particular with an unlimited and limited number of users and in the limiting mode, make it possible to solve a broad range of problems involved in developing measures for ensuring speed of communications. The employment of nomograms not only considerably shortens the time for making calculations which are very cumbersome, and in certain instances impossible by the analytical method, but also makes it possible to easily vary parameters of the system and information flow while seeking compromise solutions, both in the creation of communications systems and in improving and utilizing them. When using nomograms it must be taken into account that they are calculated for a Poisson distribution of messages entering communications facilities.

A key, more promising trend with regard to achieving the required speed (efficiency) of communications is the automation of the communications process, facilities, complexes and the communications system as a whole and of the preparation of messages for transmission (cf. chaps 8, 9 and 10). Also important trends are the following: improvement of the structure of communications systems; the elimination of retransmission stations, and, when necessary, the replacement of them with radio relay stations and the employment of facilities and methods for organizing communications which enable maximum carrying capacity (cf. Appendix 1); improvement of transmission rates; the installation of communications facilities directly at the work places of official personnel; the remote control of communications facilities; the utilization of formalized documents for the transmission of orders, reports and notices.

Thus, speed of communications is achieved by the automation of communications, by a combination of technical and organizational measures, and by the skilled utilization of communications. Here calculations are made, the main one being the calculation of the number of communications channels.

Technique for Calculating the Number of Communications Channels on a Single Route

The relationships discussed for $P(>\tau)$, τ, t_k, θ, and S make it possible to calculate the number of communications channels, S, with assigned $P(>\tau_d)$ and τ_d and known parameters of communications channels and the information flow, as well as with the required indicators for the organization and utilization of communications. With an assigned number of channels, it is possible to calculate $P(>\tau_d)$, etc. Let us discuss the procedure for calculating the number of communications channels, S.

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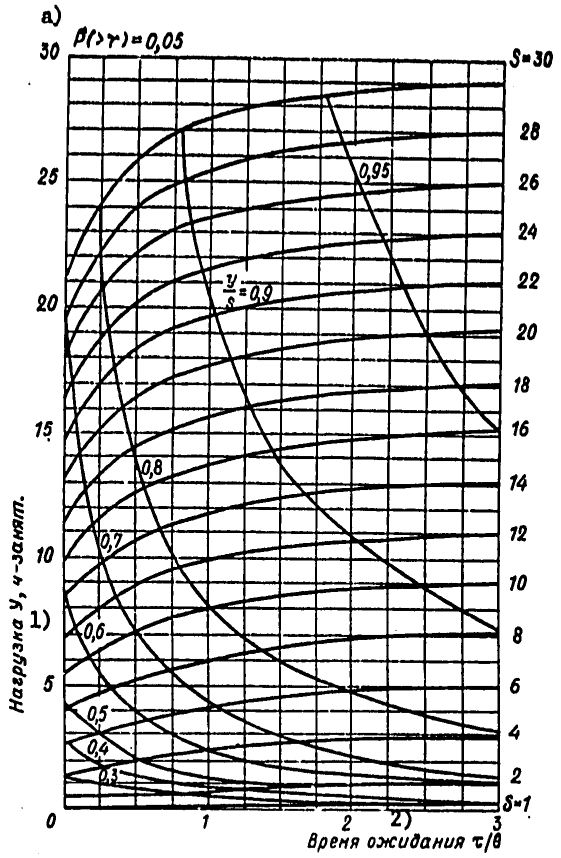

Figure 11.2a. Nomogram for Calculating Number of Communications Channels with $P(>\tau) = 0.05$

Key:

1. Load, hours occupied
2. Waiting time, τ/θ

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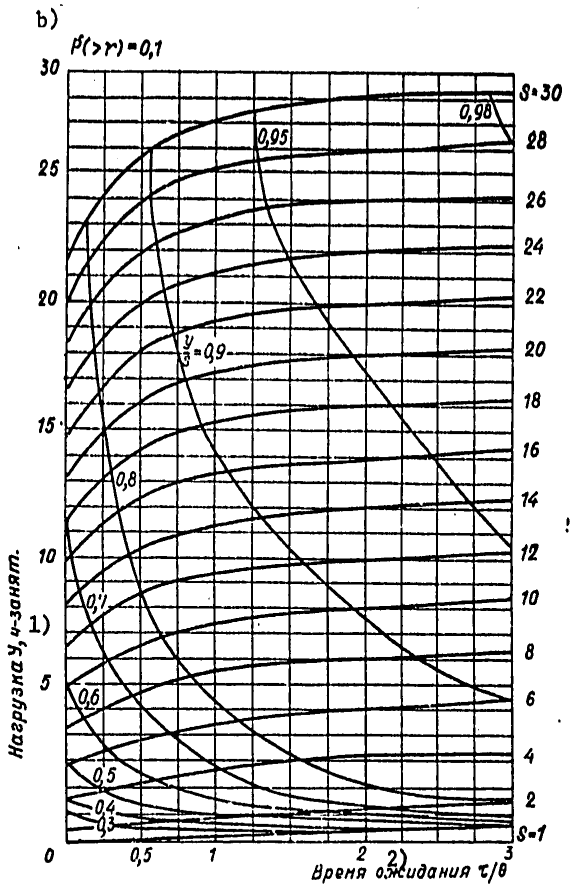

Figure 11.2b. Nomogram for Calculating Number of Communications Channels with $P(>\tau) = 0.1$

Key:
1. Load, hours occupied
2. Waiting time, τ/θ

For making calculations it is necessary to know the following:

1) The parameters of the information flow on the route in question, in particular, C_c, K_{chnn}, q and γ_q.

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2) Requirements for the speed of communications for the route in question, $t_{prokh.d}$.

3) The capabilities of communications channels, subdivisions and communications posts, in particular, V_{per} , t_{us} , t_k , t_{rk} and t_{dost} .

4) Indicators for the type of organization used and the established procedure in using communications.

Calculations are made in the following sequence:

1) A calculation is made of the time a channel is occupied in transmitting a single message, t_k .

2) A calculation is made of the load, Y , on the route in question at the hour of maximum strain.

3) A calculation is made of the amount of permissible waiting time, τ_d .

4) A calculation is made of the ratio τ/θ .

5) A classification is made of the queueing system according to which the nomogram is selected and a determination is made of the number of channels, S .

Example 1. Calculate the number of communications channels for the transmission of messages from a PU [control post] in area A to a PU in area B. $C_c = 82$; $q = 60$ groups; $\gamma_c = 0.27$ and $\gamma_q = 0.34$; $K_{chnn} = 0.25$; $t_{prokh.d} = 11$ min; $P(>\tau_d)$ not more than 10 percent. The work load and preparation of personnel and communications facilities make it possible to transmit a message in a communications channel at a rate of 18 groups per minute, and the transmission time at the communications unit is $t_{us} = 3$ min . The organization of communications has made possible one-time transmission of messages without official calls, and the official heading consists of three five-character groups.

Solution: 1. We calculate t_k from equation (1.2):

$$t_k = \frac{(3 + 60)(1 + 0{,}34^2)\cdot 1}{18} = 4 \text{ min.}$$

2. We calculate Y_{chnn} from equation (1.1):

$$y_{чнн} = 82\cdot 0{,}25\,(1 + 0{,}27)^2\cdot 4\cdot \frac{1}{60} = 2{,}2 \text{ h-occ.}$$

3. We calculate from equation (11.10) the value of τ_d . But first it is necessary to calculate from equation (11.5) $t_{prokh\ 1}$:

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4. We calculate the ratio τ/θ :

$$\frac{\tau}{\theta} = \frac{1{,}2}{4} = 0{,}5.$$

5. In this case the system involves waiting, with an unlimited number of users. Taking into account the requirement $P(>\tau) = 0.1$, we calculate the number of communications channels from the nomogram (fig 11.2b)--S = four channels.

Example 2. Calculate the number of communications channels for the same conditions, only with heightened requirements for the speed of communications, namely, with $P(>\tau)$ not equal to 0.1, but to 0.05.

Solution: From the nomogram, for $P(>\tau) = 0.05$, (fig 11.2a) we calculate S = 5 channels.

Example 3. Calculate for the conditions in example 1, but with the flow, C_c , increased to 180 messages.

Solution: 1. t_k = 4 min . 2. C_{chnn} = 45 messages ; Y_{chnn} = 3.04 h-occ. 3. $t_{prokh\ 1}$ = 10 min ; τ_d = 1 min . 4. τ/θ = 0.5 . 5. S = 7 channels .

Example 4. Calculate the number of communications channels for the conditions in example 3, whereby it is to be assumed that as the result of organizational measures carried out it has been possible to increase the transmission rate to 24 groups per minute.

Solution: 1. t_k = 3 min . 2. C_{chnn} = 45 messages ; Y_{chnn} = 3.04 h-occ. 3. $t_{prokh\ 1}$ = 9 min ; τ_d = 2 min . 4. τ/θ = 1.5 ; S = 5 channels .

These calculations graphically demonstrate how an increase in requirements for the speed of communications and an increase in the information flow cause an increase in the required number of communications channels. By carrying out organization measures it is possible to achieve a reduction in the number of communications channels, while transmitting the same information flow and not lowering the requirements for speed of communications.

Able to serve as an example of the results of carrying out a combination of measures is the improvement in communications speed in the shore system and the system of communications with MMF vessels (fig 11.3) [18]. As can be concluded from this graph, the total time for the travel of a message from a vessel to the communications unit in the existing system has reached 4.5 h and more, and the transit time 5.5 h and more; in the future "Morflot" ASU communications system this time will equal 1.4 and 1.5 h, respectively, i.e., t_{prokh} will be reduced more than threefold.

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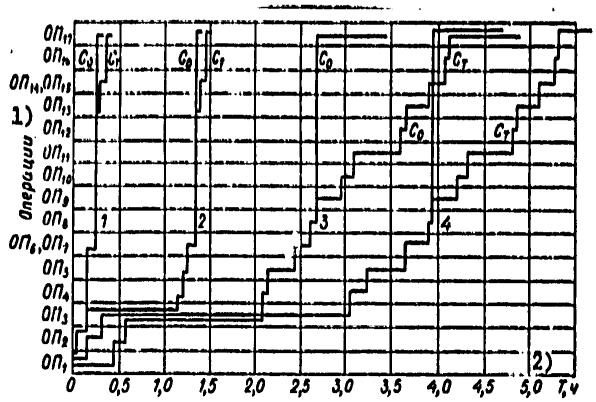

Figure 11.3. Distribution of Time for Processing a Message in the Existing MMF System and the Future "Morflot" ASU Communications System: 1--in the future shore communications system; 2--in the future "Morflot" ASU communications system as a whole, employing shortwave radio communications; 3--from port to communications unit (existing system); 4--from vessel to communications unit (existing system); C_0 and C_t--routes of ordinary and transit message; OP_1--delivery of message from user to radio station; OP_2--preparation of message for transmission (formulation, punching, etc.); OP_3--waiting for shortwave radio communications, waiting for connection in AT [subscriber's telegraph] channels; OP_4--operations for establishing communications and for entering into communications; OP_5--waiting in line to transmit a message; OP_6--transmission of message to shipping line's radio center; OP_7--reception of message by shipping line's radio center; OP_8--formulation of received message (registration, checking); OP_9--transfer of transit message to outgoing route; OP_{10}--preparation of message for transmission; OP_{11}--waiting for communications session or connection to AT; OP_{12}--operations for establishing communications; OP_{13}--waiting in line to transmit message; OP_{14}--transmission of transit message to communications unit; OP_{15}--reception of message at communications unit; OP_{16}--formulation of received message; OP_{17}--delivery of message to addressee (including waiting for courier)

Key:
1. Operations
2. T, h

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11.3. Rating Secrecy of Communications

By secrecy is customarily meant that property of communications which excludes or hampers to the maximum the obtainment by an enemy of reconnaissance data. The combination of measures for ensuring the secrecy of radio communications constitutes radio camouflaging.

The secrecy of communications can be rated quantitatively by the probability of secret communications, and the secrecy of radio communications by the probability of successful radio camouflaging, P_{rm}, the probability that an enemy in carrying out radio reconnaissance will not obtain reconnaissance data. It is numerically equal to $1 - W_{rr}$, since an enemy in carrying out radio reconnaissance solves the problem of obtaining reconnaissance information on radio communications with a probability of W_{rr}:

$$W_{рр} = P_{д рр} P_{рс} P_{д} P_{и}, \tag{11.12}$$

where $P_{c rr}$ is the probability of realizing radio reconnaissance at distance d_{rr}, i.e., the probability that at the point for carrying out radio reconnaissance the signal's field strength will equal or be greater than the strength required for radio reconnaissance facilities; P_{rs} is the probability of carrying out radio communications at the moment radio reconnaissance is carried out; P_{d} is the probability of acquiring radio reconnaissance material, i.e., the probability that operation of the radio transmitter will be detected in terms of direction or that the transmitted program or signal will be intercepted; and P_{v} is the probability of the identification of reconnaissance information from the radio reconnaissance data acquired.

The most interesting of the terms in equation (11.12) in terms of rating secrecy is the value of P_{d}, which is determined by the equation:

$$P_{д} = P_{р пер} + P_{р пел} - P_{р пер} P_{р пел}, \tag{11.13}$$

where $P_{r per}$ is the probability of radio interception of a broadcast and $P_{r pel}$ is the probability of finding the direction of an operating radio transmitter.

But for radio reconnaissance facilities with not too great a range for the detection of radio broadcasts, it can be assumed that $P_{d} \approx P_{obn}$, where P_{obn} is the probability of the detection of a radio broadcast. The probability of the detection, direction finding and interception of one of n broadcasts, the probability of determination of the location of a radio transmitting station, and also the probability of the procurement of reconnaissance data on K communications routes of a command level, P_{d_k}, and on the communications routes of M command levels, i.e., in a communications system, P_{d_m}, are discussed in [39, 70].

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Measures for combating enemy radio reconnaissance, aimed at reducing the value of $P_д$, constitute so-called passive radio camouflaging [66]. Passive radio camouflaging measures can be expressed quantitatively via the probability of non-procurement of reconnaissance data by an enemy in carrying out radio reconnaissance:

On a single route:

$$P_{\text{пр м}} = 1 - P_д; \tag{11.14}$$

On a command level:

$$P_{\text{пр м}} = 1 - P_{д.к}; \tag{11.15}$$

For an entire communications system:

$$P_{\text{пр м}} = 1 - P_{д.м}. \tag{11.16}$$

Measures for combating enemy radio reconnaissance aimed at reducing the value of P_v constitute so-called active radio camouflaging [66].

Active radio reconnaissance measures can be expressed quantitatively via the probability of the non-identification of correct reconnaissance information by an enemy from data procured, i.e., $P_{arm} = 1 - P_v$.

Consequently, the success of radio camouflaging will be determined by passive and active radio camouflaging measures and by their combination and can be rated quantitatively on the whole as follows, for command level radio communications:

$$P_{рм_к} = P_{прм_к} + P_{арм} - P_{прм_к} P_{арм}, \tag{11.17}$$

and for the communications system as a whole:

$$P_{рм_м} = P_{прм_м} + P_{арм} - P_{прм_м} P_{арм}. \tag{11.18}$$

11.4. Rating the Effectiveness of Communications on a Single Route and of a Communications System

It is possible to make a quantitative estimate of key properties of communications in terms of general or particular indicators. The choice of one indicator or another is determined chiefly by its sensitivity to a measure or study developed and carried out in a specific area. It is not hard to notice that the characteristics of communications either directly or indirectly more or less influence one another. Therefore, a measure carried out to secure one

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property simultaneously influences other properties. Furthermore, this interrelationship exerts a positive influence in some instances (for example, the higher the reliability of communications, the greater the speed of communications is increased and the number of repetitions is reduced, which in turn lowers the probability of detection, direction finding and interception), and in others, a negative influence (increasing $P_{\text{д}}$ for reliability of communications causes an increase in $P_{\text{д}}$, which increases $P_{\text{пом}}$ and can result in a reduction of $P_{\text{п}}$). This complex interrelationship is illustrated in fig 11.4, in which are shown all the key factors influencing radio communications, without taking into account radioelectronic countermeasures (REB's) (top half of sketch), and taking into account REB's (entire sketch).* In view of this complexity, the effectiveness of communications is customarily determined from a combination of the following indicators:

a) For communications of vessels and ships, without taking REB's into account, the amount of information transmitted by the communications system on the route in question; the communications range, $D_{\text{св}}$ (for communications with submarines and submerged vessels, the radio reception depth, h) and the probability of reliable communications, $P_{\text{п}}$; the average expected travel time for a message, $t_{\text{прохн}}$, and the probability of the delaying of information in the communications system, $P_{\text{зад}}$.

b) For communications of ships, taking into account REB's, the indicators cited above, and the probability of passive radio camouflaging, $P_{\text{прм}}$.**

Thus, the effectiveness of communications can be expressed by a group of several indicators. It must be mentioned that this creates certain difficulties in rating communications systems and especially in optimizing communications. Therefore, attempts have been made to find a general indicator for the effectiveness of communications. For example, the probability of the delivery of a message (a certain amount of information) in an established period with the required fidelity and secrecy and with a specific communications range under anticipated circumstantial conditions, the probability of the transmission of a message in a communications system in an established time with the required fidelity with a single broadcast, etc.

*Factors, in view of their multiplicity, are united in groups; e.g., the information flow, whose indicators are discussed in sec 1.2, is indicated by the "information flow indicators" block, and the set of data on the ionosphere discussed in chap 2, by the "propagation channel indicators" block, etc.

**Under the conditions of REB's, the values of indicators can be altered in the worse direction, but the very same indicators must be used.

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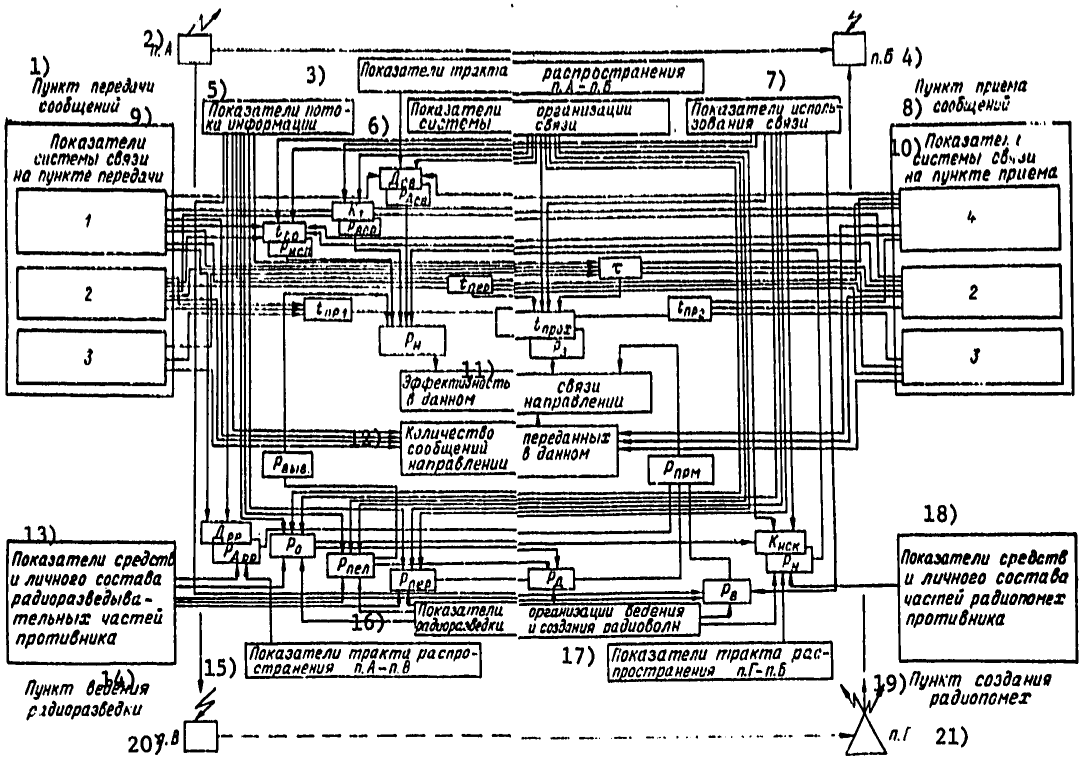

Figure 11.4. Effectiveness of Communications on a Single Route: 1--indicators for transmitting equipment (transmitting channel); 2--indicators for personnel; 3--indicators for communications posts and subdivisions; 4--indicators for receiving equipment (receiving channel)

Key:

1. Message transmission point
2. Point A
3. Indicators for point A to point B propagation channel
4. Point B
5. Information flow indicators
6. Communications system organization indicators
7. Communications utilization indicators
8. Message reception point
9. Indicators for communications system at transmission point
10. Indicators for communications system at reception point
11. Effectiveness of communications on this route
12. Number of messages transmitted on this route

[Key continued on following page]

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13. Indicators for facilities and personnel of enemy radio reconnaissance units
14. Radio reconnaissance point
15. Indicators for point A to point B propagation channel
16. Indicators for organization or radio reconnaissance and creation of radio waves
17. Indicators for point D to point B propagation channel
18. Indicators for facilities and personnel of enemy radio jamming units
19. Point for creation of radio jamming
20. Point C
21. Point D

The effectiveness of communications, discussed above, characterizes the communications system and its fitness for solving the problems posed and thus achieving its objective. For this purpose the system must possess definite properties, as indicated in chap 1.

As is obvious, they differ from the properties of communications. Consequently, a communications system will be characterized more fully and objectively by its own indicators, which differ from the indicators for communications. Furthermore, it is necessary to take into account the fact that the indicators for the properties of communications are included as necessary components in the model of the control process for vessels and in the model for the operations of controlled vessels, and the indicators for the properties of a communications system, in the model of control systems.

For the purpose of rating communications systems, it is advisable to have such indicators as a key indicator reflecting the purpose of a communications system--the transmission of information--and secondary indicators characterizing the functioning of the communications system. For example, as the key indicator can be used the productivity of the communications system, by which is meant the amount of information processed by the communications system per unit of time with specific probability and the required quality of the system's functioning. For example, according to the calculations in [72], the productivity of a system of communications with MMF vessels should be 1.5 million words per 24-hour period, and with MRKh vessels, 4 million words per 24-hour period.

The quality of the functioning of a communications system can be rated by the following secondary indicators:

1) Transmission--the probability that a specific amount of information will be transmitted over a specific range (depth, altitude) for a set time and with tolerable certainty.

2) Stability--the probability of the functioning of a communications system under enemy influence.

3) Secrecy--the probability of the non-obtainment of reconnaissance data by an enemy relating to functioning of the communications system.

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4) Economy--the cost of the system.

This approach makes it possible not only to rate the total capabilities of a communications system, but also to make an estimate while taking into account the physical cost, which is of major, and sometimes decisive, importance in the creation and improvement of communications systems.

The system possessing the best indicators will better fulfill the objectives set and thus will be more effective.

Chapter 12. Estimating the Influence of Communications on the Effectiveness of Control of Vessels and Ships

The effectiveness of communications is a component of the effectiveness of control. For its proper evaluation it is necessary to know how communications influences the effectiveness of control and to be able to estimate this influence quantitatively, which will make it possible most intelligently to solve problems relating to the design of control systems, to make a proper determination of the place of communications in the control process, and to impose requirements on communications with a good basis.

12.1. Approach to Estimating the Influence of Communications

Control generally consists in defining an intelligent combination of operations which will make possible the achievement of the appointed goal in the most effective manner. A distinction is made between the goals of the transport process, industry and combat operations and the goals of control. For example, the goal of marine transport is to convey cargo or passengers, and the goal of control of the transport fleet is to fulfill with maximum efficiency objectives in terms of transportation and revenues, both objectives set in the planning procedure and those which arise additionally [33].

For the purpose of achieving the goal of control, a set of control problems is solved, which are divided into three major groups: a) problems relating to scientifically forecasting the result of the controlled process; b) problems relating to intelligent (optimal) organization of the production process for achieving the appointed goal; c) problems relating to correction, taking into account the influence of different types of deviations from external conditions.

Sometimes the fulfillment of these control objectives is called planning (longterm--for an extended period, and current--for a short period), production and process organization, and operations control. The influence of communications is evidenced in solving control problems of all three groups, but especially strongly in operations control, since the functioning of marine transport, the fishing industry and VMF ships is highly dependent on the operating conditions of vessels and the fulfillment of objectives by ships. For example, for the fulfillment of transport objectives a number of vessels receive an assignment not according to a schedule, but according to specifically forming circumstances. Therefore, it becomes necessary efficiently to

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control the traffic of the fleet and the work load of ports to avoid economic losses resulting from the idleness of vessels, their incomplete loading and voyages in ballast, as well as from the incomplete utilization of the carrying capacity of ports [11, 33]. It is completely clear that the effectiveness of the control of vessels is directly related to communications with them. For a quantitative estimate of effectiveness, different effectiveness criteria are employed, i.e., values of W, which indicate the degree of conformity of the results of solving problems with the set goal.

In economic systems (marine transport and the fishing industry), for the purpose of determining the effectiveness criterion mathematical economic models have been developed, representing a mathematical description of the essence of production economics problems. These models are as a rule very complex and include a great amount of different data; therefore, they are run on computers. Generally a model can be represented by the following equation:

$$W = F(a_1, a_2, \ldots; x_1, x_2, \ldots), \tag{12.1}$$

where F is the operator (symbol of the model); a_1 and a_2 are information introduced into the model which can not be changed; and x_1 and x_2 are information introduced into the model which can be changed, i.e., represent the control parameter. Indicators for communications with vessels are also included in the group of control parameters.

Similar is the approach to determining the effectiveness of the control of ships, where as the criterion for this effectiveness it is customary to take the degree to which the results of the operations of ships measure up (the achieved result of operations, the cost of the result per unit or of effectiveness per unit) [8]. In general form, the model for the operations of ships can be represented by the equation:

$$W = F(X_{n1}, X_{n2}, \ldots, X_{n1}, X_{n2}, \ldots; y_{n1}, y_{n2}, \ldots, y_{n1}, y_{n2}, \ldots; Z_1, Z_2), \tag{12.2}$$

where X_n and X_p are indicators of the capabilities of our ships and of enemy forces; Y_n and Y_p are indicators of the control of our ships and of enemy forces; and Z_1 and Z_2 are indicators of the environment. Included in the group of control capabilities are the capabilities for communications with ships.

Thus, by means of models it is possible to make a quantitative determination of the influence of communications on the effectiveness of the control of vessels and ships.

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12.2. Estimating the Influence of Communications on the Effectiveness of the Control of Vessels in Solo Sailing

Success in the control of vessels depends primarily on the timely gathering, processing and transmission of a great amount of information for the purpose of optimizing processes of production or military operations. The introduction of automated control systems raises considerably the requirements for information fidelity and speed, and this is possible only with a thorough study and analysis of the transmission of messages through each element of real channels of control and communications systems.

It was demonstrated above that the effectiveness of communications systems is rated by means of individual characteristics, effectiveness indicators. These indicators are contradictory in nature, and therefore it is difficult to reduce them to a single generalized effectiveness indicator within the framework of a model under study.

A solution which would maximize any one effectiveness indicator cannot maximize the other indicators. Here it is impossible to use mathematical methods of optimization, since they make it possible to find an optimal solution only in terms of a single criterion. With the existence of but two indicators, it is possible to select a compromise solution (what price to pay to increase effectiveness or what part we will sacrifice out of other considerations) by rejecting clearly irrational variants and then sorting rational variants.

For the purpose of rating the effectiveness of a communications system it is possible to use one of the effectiveness indicators for a system of a higher level (e.g., an effectiveness indicator of the system for controlling vessels, whose operation is made possible by the communications system of a shipping line, commercial fleet, etc.). The employment of this generalizing effectiveness indicator is obvious since it makes it possible to estimate the influence of communications directly on the effectiveness of the control system. The complexity of using this model consists in the fact that the influence of communications on the outcome of control in terms of a final major effectiveness indicator occasionally is not critical, i.e., is not sensitive to a change in the parameters of the communications system being studied. This hampers the process of finding values of the system's parameters with which the communications system will operate with maximum effectiveness.

For the purpose of finding an optimal solution it is also possible to use systems of a higher level, i.e., control systems which validly govern the quantitative requirements for a communications system, according to the principle of "achieving the maximum result with specific limitations." One possible way of solving this problem is to rate a communications system by means of a generalized indicator--the probability of the timely transmission of a message upon the condition that the message will be delivered to the addressee with a probability of distortion, Q_1 , of not less than a preset value ($Q_1 \leq q_z$), and that the time for transmission of the message through the communications system, T_c , will not exceed the maximum permissible value (determined by the control system), t_{pr} :

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$$P(t_{\text{пр}}) = P\{T_{\text{с}} < t_{\text{пр}} | q_{\text{п}}, \ldots q_{\text{з}}\}, \tag{12.3}$$

Since in an ASU information is processed by computers, the requirements for fidelity are known--the probability of error must be within the range of not greater than 10^{-4} to 10^{-6}, and the measures for achieving such high fidelity are discussed in detail in Section Three. It is considerably more difficult to formulate validated quantitative requirements for a communications system with regard to speed. The time factor has always played a considerable role in any realms of control. But the role and importance of speed in communications have been changed radically today. Instead of the principle of "better late than never," to a control system has come the principle of "in time or never."

By means of the effectiveness indicator suggested for a communications system--the probability of the timely transmission of a message through the communications system--we have attempted to characterize objectively the quality of operation of a communications system by using models of the control of transport and commercial vessels.

The process of controlling vessels can be regarded as the conversion of the control system from one state to another by means of various adjusting effects. Employment of the time factor makes it possible quantitatively to judge to what extent control is efficient. For example, in traffic regulation of the flow of the arrival of vessels in ports, it is necessary, by employing adjustment effects (reassigning vessels and cargo, changing the speed of vessels in crossing at sea, issuing recommended courses by taking into account the actually existing hydrometeorological situation, etc.), to ensure coordination of the time of arrival of vessels with the freeing of moorings and the arrival of cargo in the port, which in the final result makes it possible to determine the carrying capacity and productivity of a vessel over a certain period (a voyage, a quarter, a year) [11, 31, 57].

For example, in a mathematical model for determining the net effect of a transport vessel, its annual carrying capacity is determined by the equation [31]:

$$\Pi = \sum_{i=1}^{N} \sum_{j=1}^{J_i} R_i Q_{ij}, \tag{12.4}$$

where Q_{ij} is the amount of cargo which can be transported by the vessel on the i-th freight route to the j-th port of call on the line; N is the total number of freight routes (lines); J_i is the number of ports of call on the i-th freight route; R_i is the number of voyages by the vessel on the i-th freight route per year, which is determined by dividing the length of time the vessel operates on this route (T_{ei}) by the time for the voyage (T_{ri}):

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$$R_t = \frac{T_{kt}}{T_{pt}}. \tag{12.5}$$

The time for the voyage consists of the sum of the travel time (T_{kht}) and the time the vessel is berthed in ports (T_{sti}). In turn, T_{kht} depends on the reduction in the vessel's speed resulting from specific sailing conditions (navigation, hydrometeorological or traffic control influences), and T_{sti} on the vessel's idle time for one reason or another.

Similarly, in the model for determining the net effect of a fishing vessel when fishing independently, the annual productivity of a trawler equals [57]:

$$П = \frac{365 K_и}{T_{б.п.ц}} Q, \tag{12.6}$$

where Q is the carrying capacity of the trawler in terms of annual production; K_t is the trawler's utilization factor; and $T_{b.p.ts}$ is the length of a "long" fishing cycle.

In turn,

$$T_{б.п.ц} = \alpha (T_{пер} + T_л + T_б), \tag{12.7}$$

where T_{per} is the length of time the trawler is in passage during the voyage; T_1 is the fishing period during a single voyage; T_b is the length of time for mooring at its base; and α is a factor taking into account the idle time of the trawler because of no space at moorings and hydrometeorological and other factors.

From the examples of the models cited, the role and importance of time are obvious, and it is of a probabilistic nature, and in the majority of instances the model is estimated by means of the mathematical expectation of the time for passage of the vessel at sea, mooring at its base, fish finding, trawling, or the time required for steering, for communications, for waiting for the start of the broadcasting of radio messages, etc.

Attentive consideration of these models indicates that one of the key controllable parameters is the time parameter--the time for a voyage, the length of the fishing cycle, etc. The lower the values of these parameters, the greater will be the productivity of transport or fishing vessels.

With effective control it is possible to observe the condition:

$$T_{упр} + T_{действ} < t_{пр}, \tag{12.8}$$

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where T_{upr} is the time spent on the control cycle; T_{devsty} is the time required for vessels to fulfill the objective; and t_{pr} is the maximum permissible time upon the expiration of which the activities of vessels will not result in solution of the problem posed with the required effectiveness.

Since the processes of hauling cargo or catching fish are under the influence of not only regular, but random factors, then the model of efficient control must make it possible to take them into account, to eliminate possible deviations and to make corrections every 24 hours.

In dynamic systems of this sort, the simple probability of receiving a message does not take into account the time which has passed from the moment it became necessary to transmit information to the moment it was delivered to the addressee, and therefore it ceases to be a critical indicator of the effectiveness of communications.

Information relating to adjustment effects must be periodically renewed and refined and will be of value only upon condition of timely delivery to addressees. The renewal cycle is determined by urgency categories for information transmission, which are determined by control objectives. Thus, delay in the receipt of urgent operating information can result in non-fulfillment of a required control function.

The too frequent renewal of information overloads the control system and does not make it possible to estimate the development trend of the controlled process. As a rule, intervals for the renewal of information for regular flows are determined experimentally on the basis that to each control level will be fed only the data which can be processed within acceptable deadlines and is essential for the performance of required control functions.

The greatest amount of operating information (80 percent) comes under the heading of regular traffic control information of the situation type (messages regarding the position of vessels at sea and in ports and on the arrival of vessels in ports and departure from them, 24-hour reports of fishing boats, etc.), and its growth every year is on the order of 10 percent [11]. In order to judge how efficient a system for controlling vessels is, it is necessary to make a quantitative estimate of the time factor in the transmission of traffic control information.

From the instant vessels compose messages of the situation type, they travel along a fairly complex path, depending on the arrangement employed for the control of vessels. It is possible to join in links the elements of this system for controlling single MMF and MRKh vessels when traveling at sea into unloading ports:

With the good travel of radio waves ($Q_1 \leq q_z$), into three links: ship-shore-ship.

With the poor travel of radio waves vessels always transmit messages not through the coastal radio center of their own shipping line (with $Q_1 > q_z$),

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but through any coastal radio center or intermediary vessel making possible fulfillment of the condition $Q_1 \leq q_2$; here there are four links: ship-shore-shore-ship.

We will arbitrarily represent this control system as a certain physical system which over the course of time passes from one phase state into another--$E_0, E_1, \ldots, E_n$. The process of a qualitative change in the state of the system with the passage of information through its individual elements we will call an elementary operation, and the passage of information through the entire control loop, an extended operation. Elementary operations are performed in this system, as a rule, successively, one after the other and have strictly defined interrelationships, and each succeeding event can begin only after the termination of the preceding event.

The duration of the travel of a message through each element of the system is a random magnitude depending on a whole series of factors (malfunctions of the physical component, existence of interference in the radio channel, conditions for the propagation of radio waves, reception of the message on shore directly by a radio center of its own or another shipping line, called station busy, carrying capacity of communications channels, etc.).

Let us designate via $\xi(t)$ the state of the system at moment of time t . We assume that the flow of the process depends on random factors, and the time for transmission of the message in each element of the system is distributed exponentially and the following rule is observed: If at any moment of time t the system is in phase state E_i , then at the next moment of time, t_2 , with $t_1 < t_2$, the system with probability of $P_{ij}(t_1 t_2) = P_{ij}(t)$, where $t = t_2 - t_1$, can pass into state E_j . The model described is a uniform Markov chain, and probabilities $P_{ij}(t)$ are called the transition probabilities of the Markov chain. Function $P_{ij}(t)$ defines, consequently, the probability of transition from "state i" to "state j" at the expiration of time t [9].

If at a certain moment of time $t = t_0$ Markov process $\xi(t)$ is in a certain state E_0 , then after a certain random time τ the process can pass into another state, and the probability $P(\tau < t)$ that a change in the phase state will occur not before time t will be:

$$P(\tau > t) = e^{-\lambda t}, \quad t \geqslant 0, \tag{12.9}$$

where λ is the transition density or intensity of the elementary operation.

In addition to λ , parameter $\bar{t}$ is employed, the mean time for a change in state, which is determined by the magnitude:

$$M(t) = \int_0^\infty t dP(t) = \frac{1}{\lambda}. \tag{12.10}$$

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The distribution of the probability of random magnitude τ --the time prior to the moment of transition into a new state--is such that

$$P(t_1 \leqslant \tau \leqslant t_2) = F(t_1) - F(t_2) = \int_{t_1}^{t_2} \lambda e^{-\lambda t} dt \tag{12.11}$$

with any $t_1, t_2 \geq 0$.

This is a power or exponential distribution and is expressed:

By the probability density

$$f(t, \lambda) = \begin{cases} 0 \text{ with } & t \leqslant 0, \\ \lambda e^{-\lambda t} \text{ with } & t > 0; \end{cases} \tag{12.12}$$

By the distribution function

$$F(t, \lambda) = \begin{cases} 0 & \text{with } t \leqslant 0, \\ 1 - e^{-\lambda t} = 1 - e^{-t/\bar{t}} & \text{with } t > 0. \end{cases} \tag{12.13}$$

In keeping with the effectiveness criterion we have used, expression

$$P(T \leqslant t_{np}) = 1 - e^{-\lambda t_{np}} = 1 - e^{-t_{np}/\bar{t}} \tag{12.14}$$

indicates the probability that the time for the transmission of information (T) will be greater than the specified time (t_{pr}), and expression

$$P(T \leqslant t_{np}) = \lambda - e^{-\lambda t_{np}} = e^{-t_{np}/\bar{t}} \tag{12.15}$$

indicates the probability of the timely transmission of information.

Thus, if the random magnitude characterizing the duration of an elementary operation obeys a power law or the approximate substitution is possible, of a real function of distribution of the non-power type with a power function, then the probability of the timely transmission of information over a period not greater than t_{pr} is determined by expression (12.9), and the system can be regarded as a Markov chain with continuous time and a finite number of states depending on the path along which the information travels.

Certainly the assumption of substitution of the real distribution function for the time for information transmission with a power function must be

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considered some approximation of actual conditions. Besides, in the majority of studies of a theoretical and applied nature this assumption is often employed, since it makes it possible considerably to simplify the study's mathematics and does not result in great errors which would be of practical significance.

Considering the entire process of information transmission as a Markov process, it can be assumed that after the completion of each step the system passes from one state to another over time t.

Thus is formed a chain of successive transitions, $E_0 \to E_1 \to E_2 \to E_3, \ldots, E_{n-1} \to E_n$. Such successive transitions are generally described by a system of linear differential equations (Kolmogorov equations) with respect to τ and by linear difference equations of the first order with respect to n:

$$\left.\begin{aligned} P_0'(t) &= -\lambda_0 P_0(t); \\ P_k'(t) &= -\lambda_k P_k(t) + \lambda_{k-1} P_{k-1}(t) \\ &\text{with } k = 1, 2; \quad k < n; \\ P_n'(t) &= \lambda_n P_n(t) + \lambda_{n-1} P_{n-1}(t). \end{aligned}\right\} \tag{12.16}$$

The initial conditions for system of equations (12.16) are $P_0(0) = 1$, $P_k(0) = 0$, and $P_n(0) = 0$.

This system of equations can be simplified and reduced to a single equation, since the states described by the system are not concurrent and for any moment of time

$$\sum_{k=0}^{n} P_k(t) = 1 \tag{12.17}$$

and, consequently,

$$P_n(t) = 1 - \sum_{k=0}^{n-1} P_k(t). \tag{12.18}$$

By using the raw data and by solving system of equations (12.16), it is possible to compute the probability of a transition from the initial state E_0 into only first state E_1:

$$P_0(t) = e^{-\lambda_0 t}, \tag{12.19}$$

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and only second state E_2 :

$$P_1(t) = a_1 e^{-\lambda_1 t} + a_0 e^{-\lambda_0 t}, \tag{12.20}$$

where

$$a_0 = \frac{\lambda_0}{\lambda_1 - \lambda_0}; \tag{12.21}$$

$$a_1 = P_1(0) - \frac{\lambda_0}{\lambda_1 - \lambda_0}. \tag{12.22}$$

After substitution, we get:

$$P_1(t) = \left[P_1(0) - \frac{\lambda_0}{\lambda_1 - \lambda_0}\right] e^{-\lambda_1 t} + \frac{\lambda_0}{\lambda_1 - \lambda_0} e^{-\lambda_0 t}; \tag{12.23}$$

into only state E_3 . Since

$$P_t(t) = a_1 e^{-\lambda_1 t} + a_0 e^{-\lambda_0 t} \tag{12.24}$$

and

$$P_2(t) = -\lambda_2 P_2(t) + \lambda_1 P_1(t),$$

then

$$\left.\begin{aligned} P_2(t) &= Ce^{-\lambda_2 t} + \frac{\lambda_1 a_1}{\lambda_2 - \lambda_1} e^{-\lambda_1 t} + \frac{\lambda_1 a_0}{\lambda_2 - \lambda_0} e^{-\lambda_0 t}; \\ P_2(0) &= C + \frac{\lambda_1 a_1}{\lambda_2 - \lambda_1} e^{-\lambda_1 t} + \frac{\lambda_1 a_0}{\lambda_2 - \lambda_0} e^{-\lambda_0 t}; \\ C &= P_2(0) - \left(\frac{\lambda_1 a_1}{\lambda_2 - \lambda_1} e^{-\lambda_1 t} + \frac{\lambda_1 a_0}{\lambda_2 - \lambda_0} e^{-\lambda_0 t}\right); \\ P_2(t) &= \left[P_2(0) - \left(\frac{\lambda_1 a_1}{\lambda_2 - \lambda_1} + \frac{\lambda_1 a_0}{\lambda_2 - \lambda_0}\right)\right] e^{-\lambda_2 t} + \\ &+ \frac{\lambda_1 a_1}{\lambda_2 - \lambda_1} e^{-\lambda_1 t} + \frac{\lambda_1 a_0}{\lambda_2 - \lambda_0} e^{-\lambda_0 t}. \end{aligned}\right\} \tag{12.25}$$

On the basis of condition (12.17),

$$P_0(t) + P_1(t) + P_2(t) + \ \ldots\ + P_n(t) = 1, \tag{12.26}$$

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whence the probability of transition of the system into the final state is:

$$P_n(t) \approx 1 - P_0(t) - [P_1(t) + \ldots + P_{n-1}(t)]. \qquad (12.27)$$

Thus, by employing equations (12.26), it is possible to compute the probability of the timely transmission of information as a function of the control arrangement used and the communications system for the duration of any time interval, and then to plot a graph for $P_n = f(t_{pr})$, and, with assigned values for $P_n(t_{pr})$, to calculate the time for adjustment effects. Consequently, probability $P_n(t_{pr})$ represents the degree of guarantee that the time for the transmission of information will end during the maximum permissible time t_{pr}, which is determined in relation to the control function assigned.

For the purpose of estimating the efficiency of control, it is necessary to know the technical capabilities of marine and coastal radio communications facilities and of operating personnel, and to determine the amount of traffic control information which will circulate daily from vessels in passage at sea and in fishing, and the maximum permissible time for the transmission of information on the basis of assigned control functions.

The main form of radio traffic on MMF and MRKh vessels up to the present time continues to be audio radio communications in Morse code. An operator's sending speed is on average 125 characters per minute (B = 20 bauds). But because of the low fidelity of marine radio channels (probability of error of $5 \cdot 10^{-2}$) the text in the majority of cases is repeated twice in transmission. In addition, a radio operator carries out calling, the transmission of call letters, "acknowledgement" of reception, and other secondary operations, as the result of which the operating speed is 25 to 30 characters per minute (B = 12.8 bauds). Marine data transmission equipment in the "Morflot" ASU and fishing industry ASU (the ASUOR) utilizes telegraph printers which make the following transmission rates possible: 400 characters per minute (B = = 50 bauds) with the "Rioni" RTA-60, and 600 characters per minute (B = 100 bauds) with the "Ressa" RTA-2B. But the operating speed in actual radio communications channels is respectively 30 and 50 bauds.

Analysis of the mean 24-hour radio traffic of MMF and MRKh vessels shows that the amount of information leaving MRKh vessels is 2.25 times greater than that from MMF vessels. The mean length of an official traffic control radio message for MRKh vessels is 40.6 words, and 24.2 words for MMF vessels [51, 72]. With the introduction of a unified form for an ASU, the total volume of marine information as compared with the current traffic control and operating information will increase on average by a factor of 2.5 [51], and in this case the mean length of an official radio message will be 50 words for MMF vessels and 100 words for MRKh.

The time for gathering information (in minutes) as a function of its volume and the rate at which it is processed in communications with a single vessel is shown in table 12.1, and with different numbers of squadrons and MRKh vessels in them, in table 12.2. Since the rate of transmission and reception

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of radio messages depends on many factors, including random factors, in MMF and MRKh marine radio lines control periods have been worked out for the transmission of official correspondence (from the moment a radio message is handed over for transmission and to the moment acknowledgement of it is received) as a function of urgency category.

Table 12.1.

1) Объем слов	2) Скорость, бод					
	100	50	30	20	16	12,8
50	0,5	1	1,7	2,5	3,1	4
100	1	2	3,3	5	6,3	8
200	2	4	7	10	12	16
300	3	6	10	15	19	24
400	4	8	13	20	25	31
500	5	10	17	25	31	40

Key:
1. Amount of words
2. Rate, bauds

Table 12.2.

2) Количество отрядов	1) Объем информации									
	3) 500 слов (5 судов)					4) 1000 слов (10 судов)				
	5) Скорость обработки информации, бод									
	B·50	B·30	B·20	B·16	B·12,8	B·50	B·30	B·20	B·16	B·12,8
1	00—10	00—16	00—25	00—31	00—40	00—20	00—33	00—50	01—02	01—20
3	00—30	00—50	01—15	01—35	02—00	01—00	01—40	02—30	03—10	04—00
5	00—50	01—25	02—05	02—35	03—15	01—10	02—35	04—10	05—10	06—40

Key:
1. Volume of information
2. Number of squadrons
3. 500 words (five vessels)
4. 1000 words (10 vessels)
5. Rate of information processing, bauds

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Traffic control information is transmitted in the "urgent" category. But in individual cases requiring an immediate decision this information can be transmitted in the "very urgent" category. For radio messages with a length of 50 words, when they are transmitted from MMF vessels to a single address, the control times are as follows (in the numerator, the "urgent" category, and in the denominator, the "very urgent"): in transmission from vessels to shore stations--3 h/15 min; in transmission between shore stations in subscriber's telegraph channels--1 h 30 min/30 min, and in radio channels--2 h 30 min/1 h 30 min; in transmission from shore stations to vessels--4 h [51]. These control times will be used as reference times in rating the timeliness of the transmission of information with single MMF vessels during passage at sea.

During the period of a control cycle, also included is the time spent by a control agency on selecting and substantiating the most effective control decision or recommendation regarding regulation of the transportation process, which equals not less than 3 h [11].

The maximum permissible time is determined by the control function in transport operations. The subject of the control effect is primarily vessels; therefore, it is important to determine the control period. A not too long control period does not make it possible to accomplish the control effect to the full extent, because of the small number of operators on the vessel and the long interruptions in communications with them. With a long control period, the opportunities are broadened of carrying out communications with vessels, and, accordingly, opportunities for control, but then the reliability of forecasting is reduced. A compromise solution must be considered a control period of 12 h, which provides for the most difficult variant of an interruption in communications with vessels (11 h with a single operator).

For the purpose of facilitating labor intensive calculations of the probability of the timely transmission of information, $P(t_{pr})$, in the control system for MMF vessels in passage at sea, the authors have developed a machine procedure according to which calculations are made with a computer.

The results of calculations are shown in fig 12.1a (for the control system as a whole, taking into account expenditures of time for analysis and substantiation of the control decision) and in fig 12.1b (for a communications system) as a function of the route for transmission of the message:

With the existence of reliable communications ($Q_1 \leq q_2$) with a radio center of one's own shipping line on a ship-shore-ship route (curves 3 and 6).

In the absence of communications with a radio center of one's own shipping line ($Q_1 > q_2$) and with relaying of the received message by another radio center through a subscriber's telegraph (curves 1 and 4) or through an audio radio channel (curves 2 and 5).

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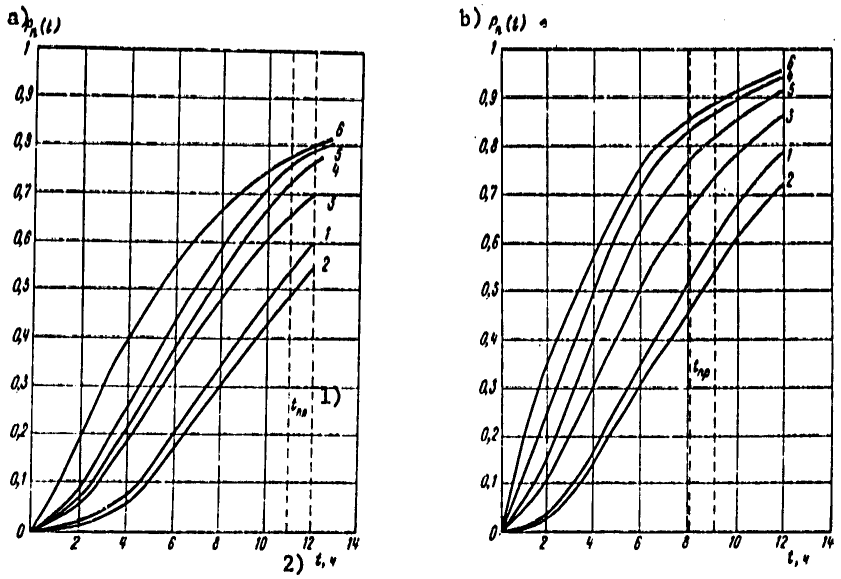

Figure 12.1. Graph of Probability of Timely Transmission of Messages in Traffic with MMF Vessels in Solo Sailing (Categories: urgent--1,2,3; very urgent--4,5,6): a--in system for control of vessels; b--in communications system

Key:

1. t_{pr}
2. t, h

An analysis of these calculations shows that if the probability of the timely transmission of a message is assigned at $P(t_{pr}) \approx 0.7$, then the transmission of a message with the "urgent" category (fig 12, curve 3) enables the fulfillment of this requirement only under conditions of reliable radio communications ($Q_1 \leq q_2$), i.e., in the reception of messages by a radio center of one's own shipping line. With the poor travel of radio waves ($Q_1 > q_2$) and the absence of radio communications with a radio center of one's own shipping line (curves 1 and 2), all traffic control information follows through a radio center of another shipping line. This causes an increase in the time for the transmission of a message, and to guarantee $P(t_{pr}) \geq 0.7$, all information of a controlled nature from vessels and to vessels must be transmitted in the "very urgent" category (curves 4, 5 and 6).

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Comparison of the timeliness of the transmission of messages through the control system as a whole and through the communications system individually shows that the latter reacts better to a change in urgency category. Whereas for the communications system, for the "very urgent" category a probability of $P(t_{pr}) = 0.84$, 0.87 and 0.89 is ensured (fig 12.1b, curves 4,5 and 6), then for the control system (fig 12.1) this same probability equals, respectively, $P(t_{pr}) = 0.76$, 0.78 and 0.81, which is explained by the identical time spent by the traffic control unit of the shipping line on analysis and substantiation of the control decision regardless of the urgency category.

The requirements for a communications system with regard to the criterion for the timeliness of the transmission of a message, $P(t_{pr}) \geq 0.9$, can be ensured by increasing radio communications channels with vessels, by employing APD with traffic speeds of not less than 300 to 400 bauds, and, in the control system as a whole, by automating the process of selecting and substantiating the control decision.

Thus, the model suggested for estimating the influence of communications on the effectiveness of control of vessels and the effectiveness indicator adopted for a communications system, $P(t_{pr}) = P\{T_c < t_{pr}\}_{Q_1 \leq q_z}$, objectively reflect the degree of achievement of a communications system of the requirements set by a system of a higher level--the control system. In addition, the model makes it possible to solve the following problems: a comparative analysis of different variants for organizing communications; an estimate of the influence on the effectiveness of control of different parameters and assigned conditions; study of individual components and elements of a control system, the disruption of whose operation has the greatest influence on the effectiveness of control. Solution of the inverse problems is also possible.

12.3. Rating the Influence of Communications on the Effectiveness of Control of Vessels in Group Sailing

MRKh vessels in group (expeditionary) fishing are controlled from the shore via a flagship. The flagship in turn controls trawlers via squadron leaders. Thus, the control effect is realized by flagships and coastal control stations.

In expeditionary (group) fishing, trawlers surrender their products to a processing and transport vessel (depot ship), which remains in the fishing ground. The effectiveness of fishing in this model depends not only on the number of vessels in the grounds, the success of the catch by each trawler, the capabilities of the depot ship with respect to the simultaneous serving of trawlers, etc. [42, 57], but also on parameters determining the efficiency of control by the flagship, such as regulation of the speed of vessels, determination of the time for them to approach the free side of the depot ship, the determination for vessels of new areas to find fish, etc.

Let us analyze an information model simulating the 24-hour gathering of information on fishing progress by vessels of the fishing fleet.

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Twenty-four hour marine reports are transmitted to vessels of a squadron and from there to the flagship, and the latter transmits the message via a shore center to the computing center of the automated system for control of the fishing industry (ASUOR).

The captains of vessels in the fishing ground write 24-hour marine reports as a rule by 1800 hours, and output information on the activities of the fleet after computer processing is presented to the management of the production or basin administration by 900 hours in the morning of the following day. About 15 h is spent on gathering and computer processing of information in the ASUOR for 24-hour marine reports, and of this about 5 to 7 h are required for entering and solving problems, processing them and delivering output data to the basin administration, and 8 to 10 h are left for the gathering of marine information by coastal radio centers.

Employing the mathematics of the theory of Markov processes in keeping with the model suggested in sec 12.2, let us make a quantitative analysis of the timeliness of the transmission of 24-hour marine reports on fishing progress in the ASUOR as a function of the number of vessels in the grounds and their organization of control, the number and processing rate of reports, and other factors.

In the calculations we will start with the fact that each medium-tonnage fishing vessel transmits a formalized 24-hour report 500 characters in length (100 words) to a vessel of a squadron and thence to a large-tonnage flagship in the audio mode (B = 12 bauds). The results of computer calculations for MRKh vessels (t_{pr} = 10 h) are given in fig 12.2a for communications between a flagships in the grounds and the shore through an audio radio communications channel, and in fig 12.2b for communications through a printing radio communications channel (ASUOR) as a function of the number of vessels fishing: five vessels in a squadron with 1, 3 and 5 squadrons (curves 1,2 and 3) and 10 vessels in a squadron with 1, 3 and 5 squadrons (curves 4, 5 and 6).

Analysis of these calculations demonstrates that it is possible to ensure the timely transmission of messages, $P(t_{pr}) \approx 0.8$ to 0.9 , from MRKh vessels in an expeditionary fishing group if with five vessels in a squadron the number of squadrons is not more than three (fig 12.2a, curves 1 and 2), and with 10 vessels in a squadron, not more than one squadron (curve 4). The changeover to the use of printing radio communications in the ASUOR (fig 12.2b) will make it possible to ensure the timely transmission of messages by uniting five vessels in a squadron with as many as five squadrons (curves 1 to 3) or by uniting 10 vessels in a squadron with as many as three squadrons (curves 4 and 5). It is not advisable to unite vessels in five squadrons of 10 vessels each, since this arrangement provides low efficiency of control ($P(t_{pr}) \approx$ $\approx$ 0.45 to 0.55).

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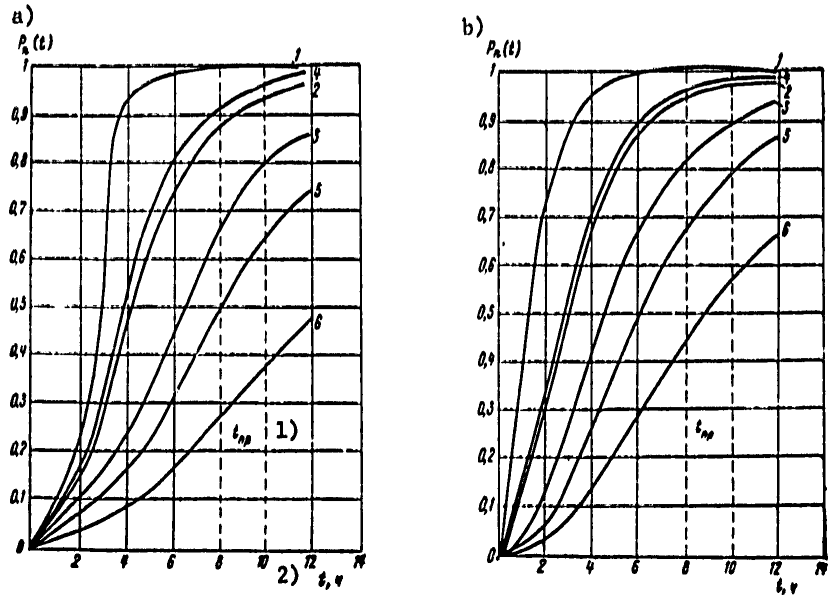

Figure 12.2. Graph of Probability of Timely Transmission of Messages from MRKh Vessels in Group Fishing: a--with audio radio communications; b--with printing communications

Key:
1. t_{pr}
2. t, h

Thus, the model suggested makes it possible to recommend measures ensuring the fulfillment of a control system's requirement for the timeliness of the gathering of traffic control information, e.g., of not lower than 0.9 to 0.95. This is possible on one hand by reducing the number of vessels in a squadron or by having a number of squadrons whereby the total time for the transmission and processing of information at all levels will be minimal, and, on the other hand, by the general changeover to the utilization by vessels of high-speed radio printing communications.

The influence of communications on the effectiveness of the control of a group of vessels or ships can be traced also in search operations frequently encountered in the activity of vessels of transport and fishing fleets and of ships of the naval fleet. Especially significant in this respect is searching by calling. Let us consider a general case.

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At the PU [control station] for a group of vessels or ships a message is received (report, notice) regarding a vessel which requires assistance, or regarding the detection of a school of fish, a submarine, enemy ship (or group of ships), and the like, i.e., regarding the object of a forthcoming search, or, as it is customarily called, a target. An order to search can be received, with an indication of the reference (suggested) location of the target. Based on the communication or order, the decision is made to search, the necessary calculations are made, and orders are issued to search vessels and ships.

The time for transmission of the message to the PU, t_{sv1}, the time for making a decision, making calculations and preparing orders for ships, t_{PU}, and the time for conveying them to ships, t_{sv2}, constitute the time of the control cycle (t_{upr}), i.e.,

$$t_{упр} = t_{св1} + t_{пу} + t_{св2}. \tag{12.28}$$

Vessels and ships or groups, having received the orders, proceed into the search area at increased speed, V_{per}, and then upon the signal are reorganized into a front arrangement and begin to search for the target at a speed of V_k. Here the search will be most complicated in the case when the target conducts itself actively, in particular, if it first detects the search ships at distance $D_{k.ukl}$ and makes a maneuver to escape them, i.e., changes its course and speed.

Particular indicators of the effectiveness of the control of search ships or vessels can be the probability of their being guided to the target, and, for reliable encountering of the target, the patrol of vessels or ships and their search time.

For reliable encountering of the target when searching by calling, N search vessels are needed, the number of which is determined by a great number of factors, including time t_{sv1} and t_{sv2}. In many cases the effectiveness of search operations is rated also by the length of the search, t_p, whose value also is determined by t_{sv1} and t_{sv2}.

And so, search vessels or ships carry out a search in front formation. As can be concluded from fig 12.3, for point of encounter C on the line of encounter the following equation must be observed:

$$\frac{IL_0C}{AI_0C} = \frac{V_uT}{V_kT} = \frac{1}{m}.$$

With $m > 1$, the line of encounter will be an ellipse, with $m = 1$, a parabola, and with $m < 1$, a hyperbola.

If V_{ts}, when the target escapes the search vessels after detection at a distance of $D_{k.ukl}$ from the line of the front, is less than V_k, then,

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according to [46], the width of zone $2F_{obs}$ which the target cannot escape equals:

$$2F_{obs} = (N-1)d + 2D_{k.ukl}\sec Q - 2D_k \operatorname{tg} Q, \tag{12.29}$$

where N is the number of search vessels or ships, d is the distance between vessels or ships, $D_{k.ukl}$ is the mean range of detection of the target by search vessels or ships, and Q is the critical angle, equal to $Q = \arcsin V_{ts.ukl}/V_k$.

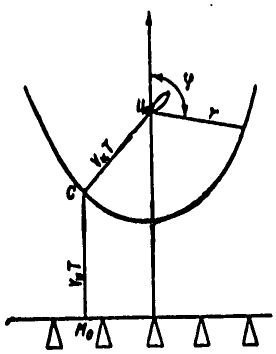

Figure 12.3. Geometrical Location of Points of Line of Encounter of Search Vessel or Ship Front with the Target

From equation (12.28) it is possible to determine the value of N--the number of search ships enabling certain encounter with the target when searching in front formation:

$$N = \frac{B_p + 2D_{k.ukl} \operatorname{tg} Q - 2D_{obs}\sec Q}{d}, \tag{12.30}$$

where B_r is the width of the search area; $D_{k.ukl}$ is the range of detection by the target of search ships and of its making a maneuver to escape, by changing its course and speed.

The magnitude of B_r is determined by the speed of the target, V_{ts}, and the search speed of the ships, V_k, to which the ships change with a transition speed of V_{per} when they are at the so-called normalized distance, D_{pr}:

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$$B_p = \frac{D_{пр}}{\sqrt{\left(\frac{V_к}{V_ц}\right)^2 - 1}} + 2f, \tag{12.31}$$

The "normalized" distance, D_{pr}, is the conventional initial distance between the target and search ships with which they, following in opposition at speeds of V_{ts} and V_k, approach at a distance of $D_{k.ukl}$ at the same moment and at the same point as if the search ships had traveled at the increased speed with which their crossing into the search area was carried out:

$$D_{пр} = D_0 - D_{к.укл} - t_{пер}(V_{пер} - V_к) - t_{постр} \times \\ \times (V_{постр} - V_к) + V_к t_{упр}, \tag{12.32}$$

where D_0 is the actual distance between the point of detection of the target and the initial location of the search vessels or ships; t_{per} is the time for the vessels or ships to cross over into the search area at increased speed, V_{per}; t_{postr} is the time spent by the vessels or ships in arranging in search formation; and V_{postr} is the speed of the search ships' governor when rearranging into search formation.

The time for the ships to cross over into the search area depends on several factors, including the time of the control cycle:

$$t_{пер} = \frac{D_0 - f - V_ц(t_{упр} + t_{постр}) - V_{постр} t_{постр} - D_{эф}}{V_{пер} + V_ц}, \tag{12.33}$$

where D_{ef} is the mean (effective) range of detection of the target, equal to the mathematical expectation of the range of detection under specific conditions.

Thus, by changing the value of the time for the transmission of reports, t_{sv1}, and orders, t_{sv2}, we change t_{upr} and from equations (12.30) to (12.33) we can arrive at the changes in the number of search vessels or ships, N, if we use as the particular indicator of the effectiveness of the operations of the ships the search time, t_p, which is determined by the delay time, t_{zap}. The delay time is determined by the time of the control cycle (t_{upr}) and the time for crossing over (t_{per}) and arranging (t_{postr}):

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$$t_{\text{п}} = \frac{2V_{\text{ц}}t_{\text{зап}} + D_0 + 2f}{V_{\text{к}} - V_{\text{ц}}}; \tag{12.34}$$

$$t_{\text{зап}} = t_{\text{упр}} + t_{\text{пер}} + t_{\text{постр}}. \tag{12.35}$$

In individual cases we are interested in the length (depth) of the search area, L_r, which also depends on the communications time, since

$$L_{\text{р}} = V_{\text{к}}t_{\text{п}}. \tag{12.36}$$

For the purpose of determining the numerical values of N, t_p and L_r, we will use as the raw data the data given in [46] for calculating N.

Ships are given the task of searching for a target detected 20 miles (D_0) from their initial location. The maximum error at the point of detection of the target is f = 1 mile and the expected speed of the target is V_{ts} = 5 knots, and when escaping $V_{ts.ukl}$ = 7 knots. The target begins to evade the search ships at a distance of $D_{k.ukl}$ = 6 miles. The speed of the search ships in crossing over is V_{per} = 32 knots, and in searching, V_k = = 18 knots. The speed of the governor when arranging in search formation is V_{postr} = 24 knots.

The time for the ships to arrange in search formation is t_{postr} = 12 min = 0.2 h. The mean range of detection of the target by the search ships is D_{ef} = 1.5 miles, and the distance between ships is d = 3 miles.

On the basis of these data we take different times for t_{sv1}, t_{sv2} and t_{PU}, which as a sum would equal the time of the control cycle over a broad range from zero (the ideal case) to 2 h, and we make calculations according to equations (12.30 to (12.36). The results of these calculations are given in fig 12.4.

An analysis of the change in values of the particular indicators of the effectiveness of the operations of ships as the result of a change in the time for the transmission of messages, and, consequently, t_{upr}, demonstrates the following:

1` An increase in the time for transmission for ensuring reliable searching for the target brings about an increase in the number of search ships (for the conditions of the example, increasing t_{upr} from 3 min to 2 h requires increasing the ships from 5 to 12), the search time (for conditions of the example, from 2.2 to 3.9 h), and the extent of the search area (from 40.6 to 70.4 miles).

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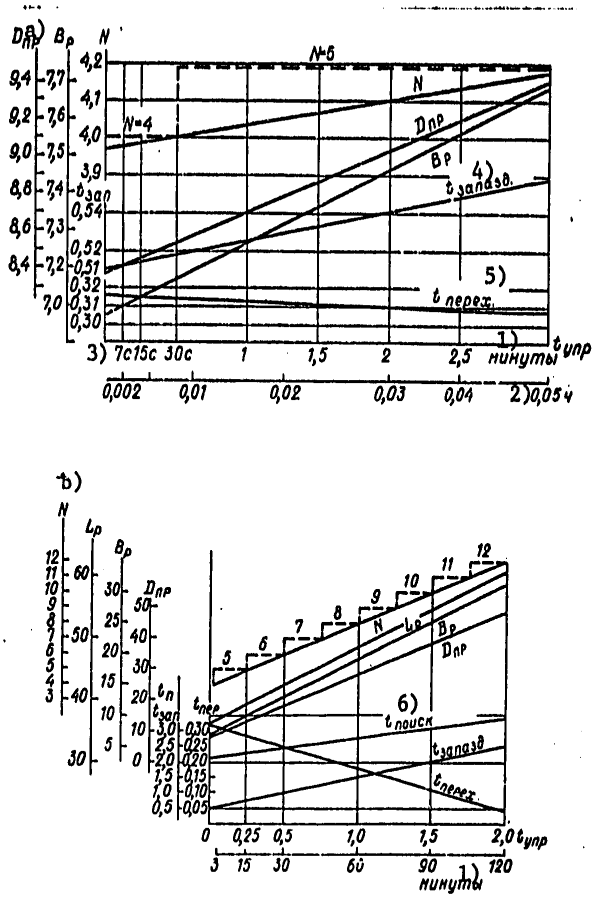

Figure 12.4. Graph of Dependence of the Number of Search Ships, N, the Search Time, t_p, and Other Characteristics of Search Operations on the Time of the Control Cycle, t_{upr}, with Variation over the Range of: a--0 to 3 min; b--3 to 120 min (for hypothetical example)

Key:

1. Minutes
2. 0.5 h
3. 7 s
4. t_{zapazd} [delay]
5. t_{perekh} [crossover]
6. t_{poisk} [search]

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2) Reducing the time of the control cycle, in particular, the time for the transmission of reports and orders, is equivalent to reducing the number of ships taking part in the search and the search time for reliable searching out of the target. A comparison of the cost of search ships and the cost of improving the control system, and in particular the communications system, testifies to the rationality of improving the communications system.

On the whole, the influence of communications on the effectiveness of control is determined in relation to the fulfillment of necessary operations in the course of solving a specific problem. For example, the effectiveness of control depends on elucidation of the situation in the area of operations, on the work of the PU in developing solutions and on the enactment and fulfillment of a particular decision by the controlled vessels or ships. And in each component of this process of fulfilling an objective it is necessary to determine the influence of communications, the total effect of which is expressed in a change in effectiveness indicators.

Conclusion

The scientific and technological revolution has made it necessary to improve control systems and, in particular, systems for communications with vessels and ships.

It has been recognized that it is advisable to develop communications facilities for vessels and ships only as part of the complex of a specific communications system, whereby unification is achieved not only of modules and facilities, but of communications complexes as a whole, too. The creation of new communications complexes and systems has made it necessary to develop also new forms for the organization of communications, new methods and procedures for utilizing it, which, in turn, governs the urgency and importance of scientific research and theoretical developments relating to systems as a whole and the organization and utilization of communications, which will ensure its maximum effectiveness under the anticipated conditions for carrying out communications at sea. All this requires special theoretical knowledge formed into an independent system of knowledge--the theory of communications at sea--which embraces a broad range of questions relating to communications at sea.

The generalization of domestic and foreign know-how in solving problems relating to communications at sea and their systematic exposition with reference to published data performed by the authors in this book embrace only the most important and specific problems, in our opinion.

If this book contributes to some extent to the formation of a theory of communications at sea, then the authors will consider their work justified.

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Appendix 1

Type of operation (transmission class)	K_1, dB	K_1, times	F, kHz
Telegraph A1 (amplitude keying)			
Low-frequency aural reception, 8 bauds	-4	0.63	3
Good-quality aural reception, 24 bauds	11	3.55	3
Automatic (printing) reception, 120 bauds	10	3.16	0.6
Printing telegraph reception, 50 bauds	16	6.31	0.25
Telegraph A2 (amplitude keying)			
Low quality, 8 bauds	-4	0.63	3
Good quality, 24 bauds	11	3.55	3
Single-sideband with carrier suppression, A2			
Single-sideband with full carrier, A2N			
Telegraphy F1 (frequency keying)			
Typing reception, 120 bauds	4	1.59	1.5
Printing reception, 50 bauds	10	3.16	1.5
Double frequency telegraphy, F6	10	3.16	2
Facsimile telegraphy, F4 (direct frequency modulation of carrier, facsimile)	15	5.62	3
Telephony AZ			
Two-band, of minimally acceptable quality (for 90 percent intelligibility of unconnected words)	6	1.99	6
Two-band, of acceptable quality	15	5.62	6
Two-band, good quality	33	44.67	6
Single-sideband with full carrier, AZN			
Single-sideband, attenuated carrier, AZA	33	44.67	3
Single-sideband, carrier suppressed, AZJ			
Radio broadcasting AZ	40	100	10
Telecode transmission, bauds (computer to computer)			
50-75	16	6.31	0.25
600-1200	16	6.31	3
12,000	16	6.31	12
48,000	16	6.31	48
Television transmission, A5, F3	15	5.62	$7 \cdot 10^3$

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Appendix 2

Номер диапазона волн (частот) 1)	Наименование диапазона 2)		Границы диапазона 5)		Способ распространения 6)		
	3) радиоволн	4) радиочастот	радиоволн	радиочастот	на близкие расстояния (до 100—200 км) 7)	на большие расстояния 8) 9) днем	10) ночью
2		Сверхнизкие (СНЧ) 11)	10000—1000 км	30—300 Гц 12)	Земные и ионосферные волны 13)	Ионосферные волны 14)	Ионосферные волны
4	Мириаметровые Сверхдлинные (СДВ) 19)	Очень низкие (ОНЧ) 28)	100—10 км	3—30 кГц 38)	Земные и ионосферные волны	Ионосферные волны	Ионосферные волны
5	Километровые Длинные (ДВ) 20)	Низкие (НЧ) 29)	10—1 км	30—300 кГц	Земные и ионосферные волны	Ионосферные волны	Ионосферные волны
6	Гектометровые Средние (СВ) 21)	Средние (СЧ) 30)	1 км — 100 м	0,3—3 МГц 39)	Земные волны 15)	Земные волны	Ионосферные волны
7	Декаметровые Короткие (КВ) 22)	Высокие (ВЧ) 31)	100—10 м	3—30 МГц	Земные волны	Ионосферные волны	Ионосферные волны
8	Ультракоротковые: Метровые (МВ) 23)	Очень высокие (ОВЧ) 32)	10—1 м	30—300 МГц	Земные волны	Тропосферные и ионосферные волны 16)	Тропосферные и ионосферные волны
9	Дециметровые (ДЦВ) 24)	Ультравысокие (УВЧ) 33)	1 м — 1 дм 37)	300—3000 МГц	Земные волны	Прямые и тропосферные волны 17)	Прямые и тропосферные волны
10	Сантиметровые (СМВ) 25)	Сверхвысокие (СВЧ) 34)	10—1 см	3—30 ГГц 40)	Земные волны	Прямые и тропосферные волны	Прямые и тропосферные волны
11	Миллиметровые (ММВ) 26)	Крайне высокие (КВЧ) 37)	10—1 мм	30—300 ГГц	Прямые волны 18)	Прямые волны	Прямые и тропосферные волны
12	Децимиллиметровые (ДММВ) 27)	Гипервысокие (ГВЧ) 36)	1—0,1 мм	0,3—3 ТГц	Прямые волны	Прямые волны	Прямые и тропосферные волны

41 42 43 43 44) 45) 46) 47) 48) 48) 48)

[Key on following page]

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Key:

1. Number of wave (frequency) band
2. Name of band
3. Radio wave
4. Radio frequency
5. Band limits
6. Method of propagation
7. Close range (to 100 to 200 km)
8. Long range
9. Day
10. Night
11. Ultralow (ULF)
12. 30-300 Hz
13. Ground and ionospheric waves
14. Ionospheric waves
15. Ground waves
16. Tropospheric and ionospheric waves
17. Direct and tropospheric waves
18. Direct waves
19. Myriametric ultralong (SDV)
20. Kilometric long (DV)
21. Hectometric medium (SV)
22. Decametric short (KV)
23. Ultrashort metric (MV)
24. Decimetric (DTsV)
25. Centimetric (SMV)
26. Millimetric (MMV)
27. Decimillimetric (DTsMV)
28. Very low (VLF)
29. Low (LF)
30. Medium (MF)
31. High (HF)
32. Very high (VHF)
33. Ultrahigh (UHF)
34. Superhigh (SHF)
35. Extremely high (EHF)
36. Hyperfrequency
37. 1 m to 1 dm
38. 3 to 30 kHz
39. 0.3 to 3 MHz
40. 3 to 30 GHz
41. Utilization of radio waves in marine communications
42. For global radio communications in the shore to submarine direction
43. For global radio communications in the shore to submarine and shore to ship direction; transmission of precise frequencies and unified time signals; radio broadcasting; transmission of navigation information
44. For transmission of distress, urgency and security signals and navigation information; for radio traffic and broadcasting
45. For global radio communications, calling and traffic on all routes; transmission of distress, urgency and security signals and navigation information; radio broadcasting
46. For traffic in ship to shore and ship to ship direction; road, port and intrasquadron communications and radio broadcasting; meteor reflection and scattered reflection communications; television
47. Tropospheric radio communications; radio relay communications on shore; television; space radio communications
48. Space radio communications

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